CALIFORNIA FISH AND GAME

"CONSERVATION OF WILDLIFE THROUGH EDUCATION"

VOLUME 56 APRIL 1970 NUMBER 2

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CONTENTS

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DISTRIBUTION OF STURGEON LARVAE IN THE SACRAMENTO-SAN JOAQUIN RIVER SYSTEM[1]

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Yolk sac stage white sturgeon, *Acipenser transmontanus*, and/or green sturgeon, *A. medirostris*, were collected from the Sacramento-San Joaquin river system, California, during the spring in 1966, 1967, and 1968. Total catch ranged from 9 sturgeon in 1966 to 76 sturgeon in 1967. The larvae were captured from the Sacramento-San Joaquin Delta and from the Sacramento River. Numbers of larvae collected in the Delta were related to the amount of flow into the Delta. This suggests that virtually all spawning occurred upstream. Water temperature ranged from 14 to 22 C when the larvae were caught. Catches by nets set at different depths gave evidence that the larvae are demersal.

INTRODUCTION

Larval white sturgeon and/or green sturgeon were collected from the Sacramento-San Joaquin river system by the California Department of Fish and Game in 1966, 1967, and 1968. Until then virtually nothing was known about the time or place of spawning. Sturgeon larvae were collected in the Sacramento-San Joaquin Delta in 1966 and 1967 by the Delta Fish and Wildlife Protection Study. The Delta Study sampled but caught no larvae in 1968. Larvae were collected from the Sacramento River in 1968 by the Inland Fisheries Branch Sturgeon and the Striped Bass Study.

The Delta Study caught the sturgeon incidental to a study of striped bass, *Morone saxatilis*, egg and larval mortality rates. The Inland Fisheries Study was sampling specifically for sturgeon larvae.

METHODS

Delta Study

Sampling was with cone-shaped tow nets. These nets were about 10.5 ft long and 2.5 ft in diameter at the mouth. They tapered back to a collecting bucket about 3 inches in diameter. In 1966 the front half of the net was constructed of $\frac{1}{4}$-inch stretch mesh nylon webbing. The back half was 20-mesh/inch nylon marquisette. In 1967 and 1968 the entire net was built of 20-mesh marquisette.

[1] Accepted for publication September 1969. Funds for this investigation were provided by the California Department of Water Resources in cooperation with the California Department of Fish and Game Delta Fish and Wildlife Protection Study and by Dingell-Johnson Project California F-9-R, "A Study of Sturgeon and Striped Bass", supported by Federal Aid to Fish Restoration funds.

[2] Now with Anadromous Fisheries Branch.

We fished for 10 min at each station. All tows were diagonal. The nets were dropped to the bottom, then winched to the surface while the boat was moving ahead.

Each sample was preserved in formalin and fish larvae were sorted from detritus and other organisms in the laboratory. Larvae were measured to the nearest 0.1 mm SL.

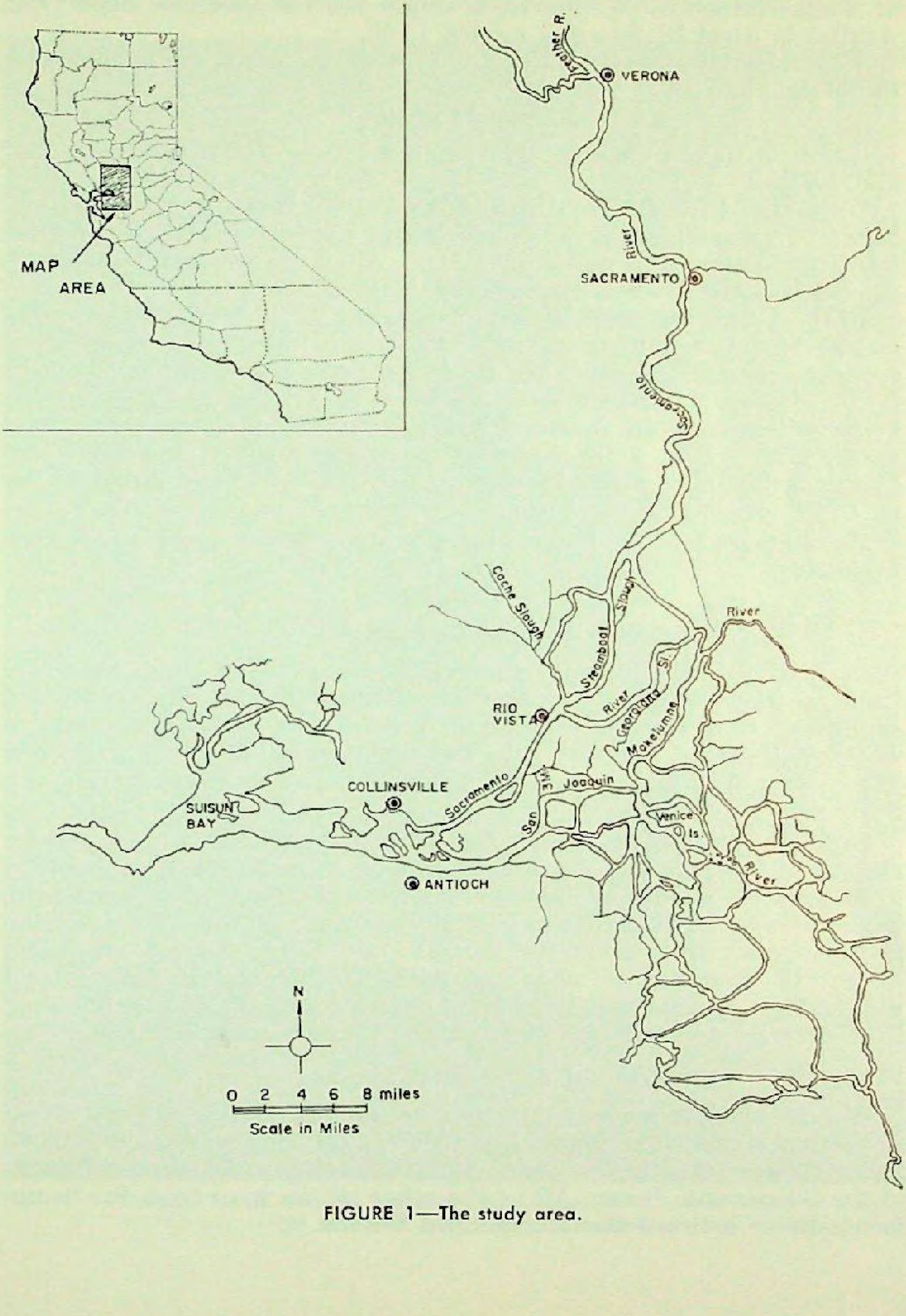

FIGURE 1—The study area.

Effort varied between years. In 1966 we had stations at 1-mile intervals from lower Suisun Bay to Rio Vista on the Sacramento River and to Venice Island on the San Joaquin River (Figure 1). We towed a pair of nets at 30 stations almost daily from April 9 to June 28. The season's samples totaled 4,072. We towed almost daily again in 1967 but collected only one sample per station. We had 1,523 samples. They were taken between April 25 and June 27. In 1968 our stations were at 2-mile intervals. We towed a single net on alternate days from April 3 to June 28. Samples totaled 1,150.

Water temperatures in the Delta were measured with recording thermographs.

Inland Fisheries

Our nets were identical to those used by the Delta Study in 1967 and 1968.

We sampled from March 27 to June 3, 1968. Between March 27 and April 11 we sampled in the Delta and in the Sacramento River from Sacramento upstream to Verona. After April 11, we sampled only in the Sacramento River at Sacramento.

In the Delta, we towed a pair of nets for 17 to 20 min. They were on the bottom for 10 min, and 7 to 10 min more were required to retrieve them to the boat. We made 33 tows. The samples from the upper Sacramento River were collected by setting the nets on the river bottom from an anchored boat. There they strained the current for 20 min to 1 hr. A few early sets were also made at mid-depth and at the surface. We made 24 sets up to April 11. After April 11 we made 69 sets, all on the bottom.

We measured water temperatures with a thermometer while sampling.

RESULTS

Catch by Delta Study

In 1966 we caught nine sturgeon larvae. Of the nine, two were from the Sacramento River between Collinsville and Rio Vista, and seven were from the San Joaquin River. The first was caught on April 13, the 5th day of sampling; the last was caught on May 27. On May 14 we caught three larvae. No more than one was caught on any other day.

In 1967 we caught 76 larvae. This was more than eight times greater than the 1966 catch, and we made this catch with less than half the 1966 effort. Fifty-seven of these larvae were from the Sacramento River between Collinsville and Rio Vista and 13 were from Suisun Bay; only six were from the San Joaquin River. Four larvae were caught the first day of sampling, April 25. Twenty-one larvae were caught May 3. This was the largest number caught on any one day. The last larva was collected June 10. In 1968 we caught no larvae.

Catch by Inland Fisheries

We captured 41 larvae. Although we sampled as late as June 3, we caught no larvae after May 21. Only one specimen was caught in the Delta. It was taken in the lower end of Steamboat Slough, a tributary of the Sacramento River. All of the other larvae were from the Sacramento River between Sacramento and Verona.

Thirty-four larvae were caught in a series of 24 sets made between April 2 and April 4. One of these larvae was caught during a set upstream from the confluence of the Sacramento and Feather Rivers, demonstrating that some spawning occurs in the Sacramento River system upstream from the Feather River mouth.

This series of sets in early April also gave us good evidence that sturgeon larvae are demersal. We caught 33 larvae in 16 bottom sets. We caught only one larva in eight surface and midwater sets.

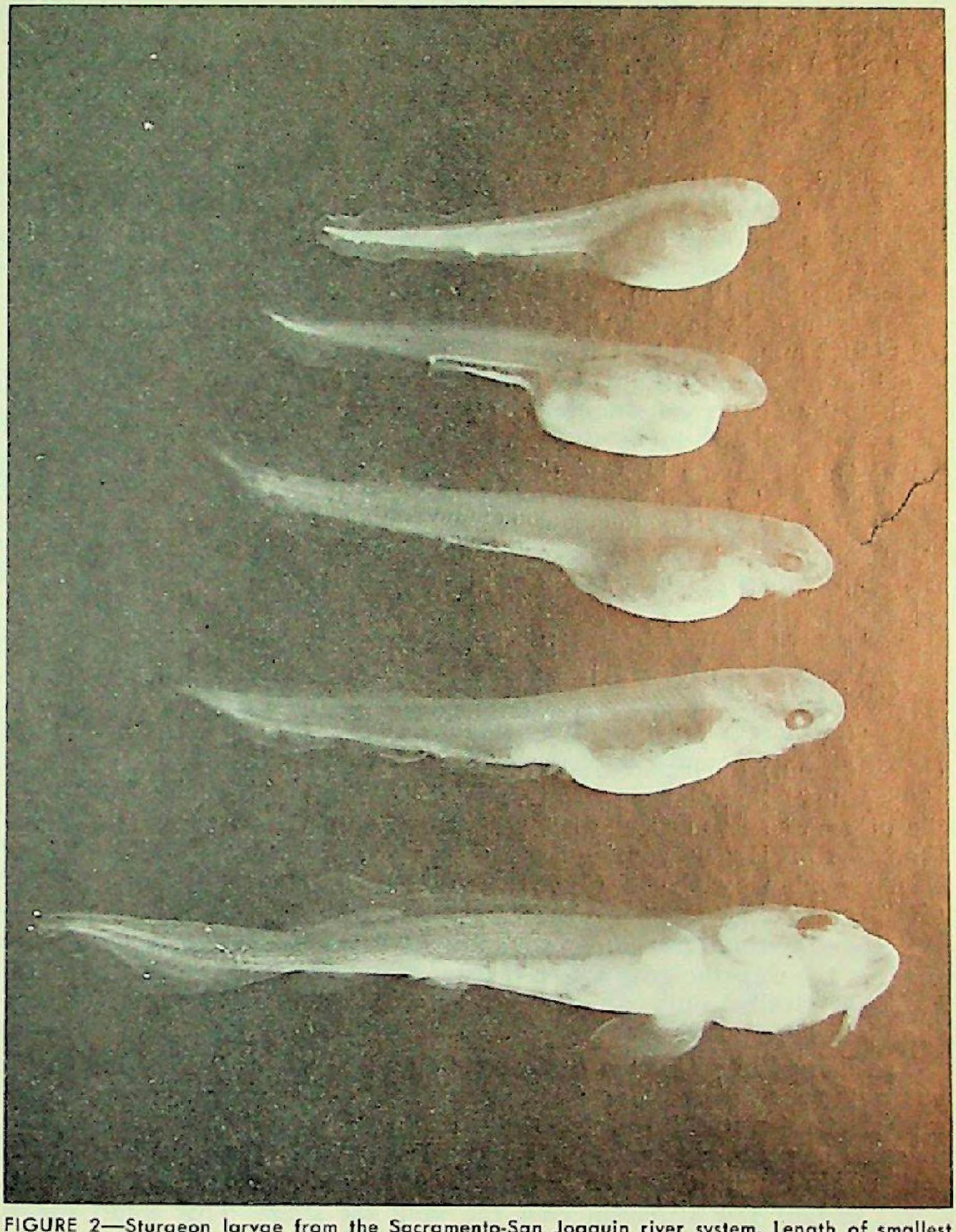

FIGURE 2—Sturgeon larvae from the Sacramento-San Joaquin river system. Length of smallest is 11.6 mm. Length of largest is 21.6 mm. *Photograph by John T. Shimizu.*

Water Temperatures

Water temperature at Antioch was about 16 C on the day the first larva was collected in 1966. The temperature was 22 C on the day the last larva was caught. This was the high for the year to that date.

We have no Delta water temperatures for 1967 until May 2. This was 7 days after we started sampling and also 7 days after the first sturgeon was caught. The temperature at Antioch was 14 C. Temperatures were 17 to 19 C on the day the last larva was caught. However, they were even higher 2 to 3 weeks before that day, ranging up to 20 C.

Water temperature varied from 14 to 15 C during the peak catches by the Inland Fisheries Study in 1968. The highest temperature recorded on a successful sampling day was 18 C.

Larval Size and Identification

In 1966, seven larvae were measured. They were from 10.9 to 12.2 mm. Sixty-three of the 76 sturgeon caught in 1967 were measured. Two individuals were quite large. They measured 41.4 and 65.0 mm. The other 61 specimens ranged from 10.3 to 23.8 mm. Mean length of these individuals was 13.6 mm.

Larvae caught in 1968 by the Inland Fisheries Study ranged from 9.8 to 21.8 mm. Mean length was 12.5 mm.

All larvae smaller than 17.6 mm had yolk sacs. The yolk sac had been used up by all larvae longer than 18.5 mm. We caught no larvae between 17.6 and 18.5 mm.

The larvae have a large yolk sac and are darkly pigmented (Figure 2). The two large specimens caught in 1967 fit Schreiber's (1960) description of white sturgeon. None of the smaller larvae could be identified to species, so there is no way of knowing if any were green sturgeon, which are also common in the estuary.

DISCUSSION

We know of only two yolk sac sturgeon larvae collected in the Sacramento-San Joaquin river system before ours. They were collected in the Delta by Timothy Farley of the Department of Fish and Game (pers. comm.) during a survey of striped bass spawning areas in May 1965. One of these larvae was from the Sacramento River at Rio Vista; the other was from Cache Slough, 2 miles upstream from Rio Vista. Captures of larger young-of-the-year sturgeon from the Delta have been reported by Pycha (1956), Schreiber (1960, 1962), and Radtke (1966).

Because of the differences in gear used between years and the differences in the way the gear was fished by the Delta Study and the Inland Fisheries Study, only qualitative conclusions about sturgeon larvae abundance are possible.

The change in nets from 1966 to 1967 undoubtedly affected our catch, but we do not believe that the magnitude of the effect on the catch per unit of effort would be anywhere near as great as the more than 22-fold increase in catch rate. The 1967 net was about twice as efficient as the 1966 net in catching striped bass of the same size as the sturgeon larvae.

We caught few sturgeon past the yolk sac stage. This could result from high larval mortality or reduced net efficiency for the larger fish.

The survey by the Inland Fisheries Study has given us good evidence of spawning in the Sacramento River system, but we still have no evidence of spawning in the San Joaquin system. Thirteen of the 85 larvae caught by the Delta Study were taken in the San Joaquin side of the Delta, but these could have emigrated from the Sacramento River through the Mokelumne River, Georgiana Slough, and Three Mile Slough.

The catch of sturgeon larvae in the Delta was clearly related to the amount of flow into the Delta from the rivers above it. By far, the highest catch from the Delta was in 1967; in that year the April outflow past Sacramento was an extremely high 49,217 cfs.[a] In 1966 we caught a few larvae and April outflow at Sacramento was 21,820 cfs. We caught no larvae in 1968 when April outflow at Sacramento was only 13,660 cfs. This suggests that virtually all spawning was above the Delta and that the larvae caught in the Delta were transported there by the flow. It is relevant that Nikol'skii (1961) indicates that most sturgeon ascend rivers to spawn on gravel or rocky substrate. In the Sacramento River, this type of bottom occurs primarily from 120 to 220 miles above the mouth of the Feather River. Gravel substrate also occurs in the Feather River from 44 to 58 miles above its mouth.

We caught larvae in water from 14 to 22 C; however, spawning temperatures may have deviated from this range. Spawning probably occurred upstream at least a week before our catches.

Although incubation periods are not known for eggs of white and green sturgeon, they are known for some other sturgeons. Nikol'skii (1961) gives incubation periods for several species. They range from 50 hr to 5 days. The incubation period for the Atlantic sturgeon is 94 hr at 20 C (Dean, 1895) and about 168 hours at 17.8 C (Vladykov and Greeley, 1963). Atlantic sturgeon are in the yolk sac stage about 6 days (Vladykov and Greeley, 1963).

ACKNOWLEDGMENTS

We thank all those who helped with the field work. Vincent Catania, Richard Fenner, Robert McKechnie, and Salvatore Mercurio were particularly helpful. We also thank the several laboratory technicians who sorted through the gallons of samples.

We are indebted to John T. Shimizu of the Division of Biological Control, Department of Entomology and Parasitology, University of California, Berkeley, for photographing the larvae.

The manuscript was reviewed critically by Harold K. Chadwick.

[a] Outflow figures are mean monthly flow estimates by the U.S. Bureau of Reclamation.

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SHOREBIRD AND WATERBIRD USE OF THE SALTON SEA[1]

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The Salton Sea, California, has a rich avifauna. Thirty-five species of shorebirds and 47 species of waterbirds, exclusive of swans, ducks, geese, cranes, and rails, have been recorded. Birds are particularly abundant during migration periods. A complete listing of birds is given, together with comments on abundance and seasonal occurrence.

INTRODUCTION

The Salton Sea, Imperial and Riverside Counties, California, is used by immense numbers of shorebirds every year. During periods of migration many shorebirds use the sea for a stopping place to rest and feed. A large number spend the entire winter on and around the sea. Some shorebirds spend the summer; a few of them nest successfully.

Spring migrants occur in huge numbers during April and May. These birds apparently move northward up the west coast of Mexico and concentrate in the Gulf of California. The Salton Sea, situated just north of the head of the Gulf of California, is the last large body of water these birds find before they encounter the desert areas of eastern California. Spring migrants appear to remain on the sea for a week or two before moving on, apparently building up their fat resources for the long flight ahead to the northern breeding grounds. At times in late April and early May it is possible from one spot at the north end of the sea to see between 15,000 and 20,000 shorebirds feeding along the shore. Occasionally, large losses among the smaller species of shorebirds occur during spring migration. In early May 1968, 5,000 western sandpipers succumbed in the area around the mouth of Whitewater River at the north end of the sea. It is suspected that botulism may have been the cause but positive diagnosis was not made.

The fall migration is less spectacular, since it occurs over a longer period of time, but nonetheless huge numbers of shorebirds use the sea. The first fall migrants appear during the first week of July and late individuals are still passing through in November. The Salton Sea attracts shorebirds moving south along the western edge of the Great Basin and the Mojave and Colorado Deserts and many of these birds spend long periods of time on the sea before moving on. An American golden plover spent at least 6 weeks at one spot on the sea during the fall of 1967.

During the winter, large flocks of shorebirds utilize the sea and anyone visiting the area cannot help but be impressed by the thousands of American avocets along its shores.

In June, a number of summering nonbreeding shorebirds are present, along with the few species that nest at the sea. The black-necked stilt is by far the most numerous nester, but there are significant numbers

[1] Accepted for publication December 1969.

of nesting killdeer and smaller numbers of nesting snowy plovers and American avocets.

The north and south ends of the sea are the most attractive to the shorebirds and other waterbirds. Here there are large stretches of mudflats which are extremely rich in the organisms upon which shorebirds feed. Also, at the ends of the sea there are marshes and thickets of saltcedar (*Tamarix pentandra*) which provide cover to many waterbirds. The areas around the mouths of the three main rivers—the Whitewater, New, and Alamo Rivers—are by far the most productive for all waterbirds.

The east and west shores of the sea are used by only a few birds. Here the desert meets the sea along sandy beaches, where there appears to be little food to attract shorebirds. However, this habitat is attractive to migrant sanderlings during the spring migration period and a few ruddy turnstones have been found here.

At the south end of the Salton Sea there is extensive agricultural development. Frequently irrigated field crops attract large flocks of shorebirds of many species. These shorebirds use the sea as a loafing area at night and no doubt feed along the shore of the sea when no irrigation is being done. In the morning, one can see huge flights of shorebirds and gulls flying from the sea out over Imperial Valley and returning to the sea in the evening.

The following discussion lists all the shorebirds and waterbirds (excluding the Anatidae, Gruidae, and Rallidae) known to have occurred at the Salton Sea through December 31, 1968. Terms used in defining the relative abundance of each species are those used by Bull (1964):

Regular—Reported Annually	
1. Very abundant	Over 1,000 individuals per day per locality (normally in large flocks)
2. Abundant	201–1,000 individuals per day per locality
3. Very common	51–200 individuals per day per locality
4. Common	21–50 individuals per day per locality
5. Fairly common	7–20 individuals per day per locality
6. Uncommon	1–6 individuals per day per locality
7. Rare	1–6 individuals per season
Irregular—Not Reported Annually	
8. Very rare	Over 12 records, but of very infrequent occurrence
9. Casual	7–12 records
10. Accidental	1–6 records

Seasons used in the following discussion are not the seasons we normally think of, but are the seasonal periods used by the birds involved. They are: spring, April and May; summer, June; fall, July through November; and winter, December through March.

SHOREBIRDS

Semipalmated plover *Charadrius semipalmatus*

A very common spring migrant in April and May, when up to 100 individuals can be found in a day. A common fall migrant between July and early November, when up to 50 can be found in a day. Occasionally found in winter, when it is rare.

Snowy plover, *Charadrius alexandrinus*

Resident, though more numerous in the summer. Fairly common in summer, when up to 20 can be found in a day. Uncommon in the winter, when it is unusual to find more than five or six in a day. Nests at the Salton Sea.

Killdeer, *Charadrius vociferus*

A very common resident. Found primarily in the cultivated fields around the Salton Sea, where it is not unusual to find 150 or more in a day. Nests at the Salton Sea.

American golden plover, *Pluvialis dominica*

A rare spring and fall migrant. Has occurred on at least two occasions in the winter. In recent years one or two have been found in late April and early May and again between mid-July (July 16 is the earliest record) and mid-October. The two winter records are of three seen in the fields close to the south end of the Salton Sea on February 13 and March 6, 1965, and three seen in the same area on February 13 and 19, 1966.

Black-bellied plover, *Squatarola squatarola*

Present throughout the year. An abundant migrant in spring and fall, when up to 1,000 can be found in a day. Slightly less abundant in the winter, when up to 500 can be found in a day. Rare in June, when one or two nonbreeding summering individuals can usually be found.

Mountain plover, *Eupoda montana*

A very common to abundant winter visitor between mid-October and mid-March in the cultivated fields around the Salton Sea, where up to 800 have been found in a day. An individual seen at the south end of the Salton Sea on August 5, 1967, was either very early or, more likely, a summering bird.

Surfbird, *Aphriza virgata*

Accidental. Five seen at the north end of the Salton Sea on April 25, 1967, and two seen (one collected) there on April 29, 1967, are the only two records.

Ruddy turnstone, *Arenaria interpres*

A rare spring migrant and a casual fall migrant. Small flocks of up to 25 have been found in May; however, groups of two or three are more usual. A few individuals have also been found in the fall, primarily in August and early September.

Black turnstone, *Arenaria melanocephala*

Accidental. One seen on May 17, 1930, and two seen on May 2, 1964, are the only records.

Common snipe, *Capella gallinago*

An uncommon to fairly common winter visitor, varying in abundance from year to year. Found primarily along the irrigation ditches leading into the sea, where up to 15 a day can be found in a good year.

Long-billed curlew, *Numenius americanus*

Present throughout the year in varying numbers. Very common to abundant in the spring and fall. Common to abundant in winter, when up to 1,000 occasionally can be seen in a day. There are always a few summering birds present in June, when as many as 150 have been found in a single flock.

Whimbrel, *Numenius phaeopus*

Present throughout the year in varying numbers. Abundant to very abundant in the spring and fall, when flocks of up to 5,000 have been found in a single irrigated alfalfa field. Very common to abundant in winter. Small numbers of nonbreeding birds regularly are present in June.

Spotted sandpiper, *Actitis macularia*

A fairly common spring and fall migrant, but since this is not a flocking species, it is never in large numbers, though up to 15 have been found in a day. Uncommon in winter, when up to five or six can be found in a day.

Solitary sandpiper, *Tringa solitaria*

A very rare spring migrant in late April and early May. A rare fall migrant between early August and late September. It is unusual to see more than a single bird on any day, though as many as three have been seen together.

Wandering tattler, *Heteroscelus incanum*

Accidental. One seen near Red Hill at the south end of the Salton Sea on August 31, 1961.

Willet, *Catoptrophorus semipalmatus*

A very common to abundant spring and fall migrant. Very common in winter, when as many as 200 frequently are found. There are always a few nonbreeding birds present through June, when as many as 50 have been found.

Greater yellowlegs, *Totanus melanoleucus*

A common spring and fall migrant. Also common in winter, when as many as 30 or 40 occasionally can be found feeding together in an irrigated field. Very rare in summer.

Lesser yellowlegs, *Totanus flavipes*

A fairly common to common spring and fall migrant. Also fairly common to common in winter. This species appears to prefer irrigated fields to the shore of the Salton Sea and it is in irrigated fields that flocks of up to 50 have been found.

Knot, *Calidris canutus*

An uncommon to fairly common spring migrant in April and May and an uncommon fall migrant. During the spring this species has been recorded between April 29 and May 18, when up to six are found regularly; however, flocks of up to 100 have been recorded. During the fall it has been recorded between July 14 and September 18, when small numbers, up to 15 in a flock, have been found.

Pectoral sandpiper, *Erolia melanotos*

A very rare fall migrant and an accidental spring migrant. There is a handful of records for the month of October and a single individual was seen at the south end of the Salton Sea on May 18, 1968.

Baird's sandpiper, *Erolia bairdi*

A rare to uncommon fall migrant and an accidental spring migrant. During the fall this species has been recorded between June 21 and October 1, with a maximum of six together on August 22, 1965. Two seen (one collected) at the north end of the Salton Sea on April 28, 1968, is the only spring record.

Least sandpiper, *Erolia minutilla*

A very abundant migrant in spring and fall, when it occurs in immense numbers. Slightly less numerous during the winter, but even then it occurs in immense numbers and flocks of well over 1,000 are commonplace. Casual during the summer.

Dunlin, *Erolia alpina*

A common to very common fall migrant and winter visitor. A very common to abundant spring migrant. In the fall, this species is never recorded before the latter part of September and the major influx occurs during October. This species is most numerous in April and early May, when as many as 1,000 have been seen. Accidental during the summer.

Short-billed dowitcher, *Limnodromus griseus*

A common spring migrant and a fairly common fall migrant. This species is recorded regularly during April and early May in flocks of up to 50. It has also been found regularly between early July and early October in small numbers. The extreme similarity between this species and the following species makes its true status hard to determine.

Long-billed dowitcher, *Limnodromus scolopaceus*

An abundant to very abundant spring and fall migrant. An abundant winter visitor. All the available evidence indicates that this is the most numerous species of dowitcher on the Salton Sea.

Stilt sandpiper, *Micropalama himantopus*

An uncommon spring migrant. An uncommon to fairly common fall migrant. A rare to uncommon winter visitor. During the spring this species is recorded most often in April and early May and has been seen as late as May 21; normally less than six individuals are seen together, but as many as 25 have been seen together. During the fall, it has been recorded as early as August 1; flocks of over 20 are unusual, but as many as 100 have been seen together. It has been recorded regularly during the winter in very small numbers but as many as 16 individuals have been seen together in February. In the western United States this species is recorded regularly only at the Salton Sea.

Semipalmated sandpiper, *Ereunetes pusillus*

Accidental during the spring, but may prove to be regular in very limited numbers. There are four recent records between May 7 and 21.

Western sandpiper, *Ereunetes mauri*

A very abundant spring and fall migrant, when it occurs in the tens of thousands. Slightly less numerous during the winter, but even then it is still very abundant. Casual during the summer.

Marbled godwit, *Limosa fedoa*

Present throughout the year. A very abundant spring and fall migrant. An abundant to very abundant winter visitor. Common in the summer, when nonbreeders are present. Flocks of 2,000 to 3,000 are of common occurrence during most of the year.

Sanderling, *Crocethia alba*

An uncommon spring migrant and a casual fall migrant. During April and May, this species is regular in small numbers and as many as 26 have been seen in a day. There are only a few records for the fall period, primarily in August and September.

American avocet, *Recurvirostra americana*

Present throughout the year. Very abundant all of the time, but numbers are greatest during the late summer and early fall, when as many as 20,000 can be seen from one spot. A few individuals nest, but it is apparently a rather rare breeder at the Salton Sea.

Black-necked stilt, *Himantopus mexicanus*

Present throughout the year. Abundant throughout most of the year but rare to uncommon during the winter. This species is the common nesting shorebird at the Salton Sea.

Red phalarope, *Phalaropus fulicarius*

Accidental. There are four records between September 6 and November 6 and there is one record for May 12.

Wilson's phalarope, *Steganopus tricolor*

A very abundant fall migrant. An abundant spring migrant. Casual during the winter. Flocks of thousands are frequently found in the fall between early July and early October, with a few remaining in November. During the spring, this species occurs primarily in April and most are gone by mid-May.

Northern phalarope, *Lobipes lobatus*

A very common to abundant spring and fall migrant. In the spring, it is recorded primarily in late April and throughout May. During the fall, it occurs between early August and late November. Numbers appear to fluctuate from year to year.

WATERBIRDS EXCLUDING WATERFOWL

Common loon, *Gavia immer*

A rare spring migrant.

Arctic loon, *Gavia arctica*

Accidental. Two records.

Horned grebe, *Podiceps auritus*
Casual during the winter and spring.

Eared grebe, *Podiceps caspicus*
Very abundant throughout the year.

Western grebe, *Aechmophorus occidentalis*
Uncommon during the fall, winter, and spring.

Pied-billed grebe, *Podilymbus podiceps*
Uncommon during the fall, winter, and spring.

New Zealand shearwater, *Puffinus bulleri*
Accidental. One record.

White pelican, *Pelecanus erythrorhynchos*
Very common spring migrant. Common fall migrant. Fairly common during the winter and summer. Formerly bred, but does not at the present.

Brown pelican, *Pelecanus occidentalis*
Uncommon between July and October.

Blue-footed booby, *Sula nebouxii*
Very rare between July and October.

Brown booby, *Sula leucogaster*
Accidental. One record.

Double-crested cormorant, *Phalacrocorax auritus*
Fairly common to common resident. Breeds.

Magnificent frigatebird, *Fregata magnificens*
Casual during August and September.

Great blue heron, *Ardea herodias*
Fairly common to common resident. Breeds.

Green heron, *Butorides virescens*
Uncommon resident. Breeds.

Cattle egret, *Bubulcus ibis*
Uncommon to fairly common throughout most of the year. Withdraws during the summer.

Reddish egret, *Dichromanassa rufescens*
Accidental. One record.

Common egret, *Casmerodius albus*
Fairly common resident. Breeds.

Snowy egret, *Leucophoyx thula*
Common to very common resident. Breeds.

Louisiana heron, *Hydranassa tricolor*
Accidental. One record.

Black-crowned night heron, *Nycticorax nycticorax*
Common to very common resident. Breeds.

Least bittern, *Ixobrychus exilis*
Resident, though more numerous during the summer, when it is uncommon. Breeds.

American bittern, *Botaurus lentiginosus*
Uncommon during the winter.

Wood ibis, *Mycteria americana*
Fairly common to abundant between July and mid-September. Numbers fluctuate from year to year.

White-faced ibis, *Plegadis chihi*
Fairly common throughout the year. Breeds.

Roseate spoonbill, *Ajaia ajaja*
Casual during the spring, summer, and fall.

Parasitic jaeger, *Stercorarius parasiticus*
Very rare during the fall.

Glaucous-winged gull, *Larus glaucescens*
Very rare during the winter.

Western gull, *Larus occidentalis*
Rare during the later summer and fall. Accidental at other times of the year.

Herring gull, *Larus argentatus*
Common during the winter.

California gull, *Larus californicus*
Very common to abundant during the fall, winter, and spring. Uncommon during the summer.

Ring-billed gull, *Larus delawarensis*
Abundant to very abundant during the fall, winter, and spring. Uncommon during the summer.

Mew gull, *Larus canus*
Accidental. One record.

Laughing gull, *Larus atricilla*
Uncommon to fairly common between July and November. Formerly bred and may still do so occasionally.

Franklin's gull, *Larus pipixcan*
Uncommon spring and fall migrant. Accidental during the summer.

Bonaparte's gull, *Larus philadelphia*
Very common spring migrant. Fairly common fall migrant and winter visitor. Very rare during the summer.

Little gull, *Larus minutus*
Accidental. One record.

Heermann's gull, *Larus heermanni*
Casual during July and August.

Black-legged kittiwake, *Rissa tridactyla*
Accidental. Three records.

Sabine's gull, *Xema sabini*
Accidental. Two records.

Gull-billed tern, *Gelochelidon nilotica*
Uncommon between July and September, sometimes occurring as early as late March. Formerly bred and may still do so occasionally.

Forster's tern, *Sterna forsteri*
Common to very common during the spring, summer, and fall.

Common tern, *Sterna hirundo*
Uncommon spring migrant. Fairly common to common fall migrant.

Least tern, *Sterna albifrons*
Casual during the spring and fall.

Caspian tern, *Hydroprogne caspia*
Common during the spring, summer, and fall. Rare during the winter. Formerly bred and may still do so occasionally.

Black tern, *Chlidonias niger*
Abundant to very abundant during the spring, summer, and fall.

Black skimmer, *Rynchops nigra*
Accidental. One record.

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Calif. Fish and Game, 56 (2) :96–108. 1970.

INFLUENCE OF MOLYBDENUM ON THE TROUT AND TROUT FISHING OF CASTLE LAKE[1]

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The addition of 35 lb of sodium molybdate ($Na_2Mo_4 \cdot 2H_2O$) to Castle Lake, California, in July 1963 was followed by record yields to the angler of rainbow trout (*Salmo gairdnerii*) in 1966, and eastern brook trout (*Salvelinus fontinalis*) in 1967. The increase each year was approximately 3.5 lb per acre greater than the average annual yield for the period 1960–1965. Estimated cost per additional pound of trout in the creel was less than $0.10. High survival of the 1965 year class of both species was responsible for the increased yield. Greater standing crops of zooplankton and bottom fauna very likely promoted the improved survival. Changes in growth rates of trout following fertilization were not significant. The strong 1965 year classes apparently reduced survival of subsequent year classes. Factors other than fertilization may have influenced the high survival of the 1965 year classes. These include (i) the size and condition of rainbow trout when stocked, (ii) the density of resident rainbow trout when a plant was made, and (iii) a record December 1964 flood. Because of the doubts created by these factors, a second experimental molybdenum addition has been made.

INTRODUCTION

The California Department of Fish and Game has been conducting fisheries studies at Castle Lake since 1938. Until 1959, the basic objective was to evaluate various trout stocking practices. The results of this work have been described by Wales (1946), Wales and German (1956), and Wales and Borgeson (1961).

Dr. Charles R. Goldman of the Department of Zoology, University of California at Davis, working in cooperation with the Department, has been investigating the limnological characteristics of Castle Lake since 1959. His objective is to determine the effects of experimental fertilization on various aspects of the lake's limnology. The Department's role since 1959 has been to evaluate the effects of fertilization on trout and trout fishing.

A study of the elements limiting primary productivity disclosed that molybdenum was the stimulating micronutrient (Goldman, 1960). Therefore, on July 23, 1963, 35 lb of sodium molybdate ($Na_2Mo_4 \cdot 2H_2O$), containing 14 lb of molybdenum, were added to the surface water of Castle Lake. The cost of the chemical was about \$30. "Before and after" measurements were made of water chemistry, primary productivity, and the standing crop of phytoplankton, zooplankton, and bottom fauna (Goldman, 1967; Beatty, 1968; and Carlson, 1968). The magnitude of the response, particularly the increase in the standing crops of zooplankton and bottom fauna, was such that major changes

[1] Accepted for publication September 1969.
[2] Presently on leave of absence with the United Nations Food and Agricultural Organization, Jinja, Uganda.

in the trout population could be anticipated. The purpose of this report is to describe the trout population and the trout fishery before and after the addition of molybdenum.

DESCRIPTION OF CASTLE LAKE

Castle Lake is a glacial cirque lake lying at 5,600 ft in the Klamath Mountains of Siskiyou County. Steep slopes surround all but the low moraine on the north end, through which the outlet stream has cut. This 50-acre lake drains only 200 acres, and snow and numerous springs form its main water supply. The northern third of the lake is shallow and has a maximum depth of 15 ft, while the remainder is a deep bowl with a maximum depth of 122 ft.

The lake is mesotrophic, with total dissolved solids usually between 20 and 30 ppm. Secchi disk readings range from 40 to 55 ft and summer surface temperatures never exceed 75 F. A thermocline develops in the deep bowl in June, and in some years complete oxygen depletion occurs below 85 ft.

The eastern brook and rainbow trout are the only species in Castle Lake. The eastern brook reproduces over sublacustrine springs, while annual stocking supports the rainbow trout population. The rainbow does not spawn in the lake, and the tributary streams are of no value for spawning because they are short, steep, and flow briefly each year.

METHODS

The fishery was monitored by a five-day-per-week creel census similar to that described by Best and Boles (1956). All weekend days, major holidays (Memorial Day, Fourth of July, and Labor Day), and three weekdays per week were censused. No weekday was missed during any two consecutive weeks. Because of the single access road and relatively light angler use, it was possible to check virtually all anglers each census day. We therefore assumed that all anglers were contacted on these days. Missing weekday data were calculated monthly by direct expansion from known data.

Census data were collected from 1960 through 1968. In all but 1968, the fishing season began the Saturday nearest to May 1 and continued through October 31. The 1968 season, however, was extended through November 15. To compare 1968 with previous years, November data were excluded. Because of weather conditions, Castle Lake often remained inaccessible from several days to several weeks beyond the legal opening day.

Fish were measured to the nearest 0.1 inch FL and weighed to the nearest 0.01 lb.

The annual rainbow plants were standardized at 10,000 fingerlings, averaging 10 to 20 per ounce, planted in mid-August of each year. All fish were from the same strain of domesticated brood stock, and were reared at nearby Mt. Shasta Hatchery using standard hatchery procedures. Each year's plant was given a distinctive fin clip.

Since all rainbow trout were marked, individual ages were readily determined. Ages were not determined for brook trout, however.

RESULTS

Use, Success, and Yield

Substantial increases in angler success and trout yield occurred during the post-fertilization years of 1966 and 1967 (Table 1, Figure 1). The average annual catch per hour from 1960 through 1965 was 0.84, and ranged from 0.75 to 1.04. The average annual yield in pounds per acre was 12.8, and ranged from 10.9 to 14.5. Yields of 16.7 in 1966 and 16.6 in 1967 were 30% greater than the 1960–1965 mean. The 1966 success rate of 1.15 was 37% greater than the 1960–1965 mean. The 1967 value of 1.07 trout per hour, although 27% higher than the mean, was only slightly greater than the 1963 value. Yield and success for 1968 dropped to pre-1966 levels.

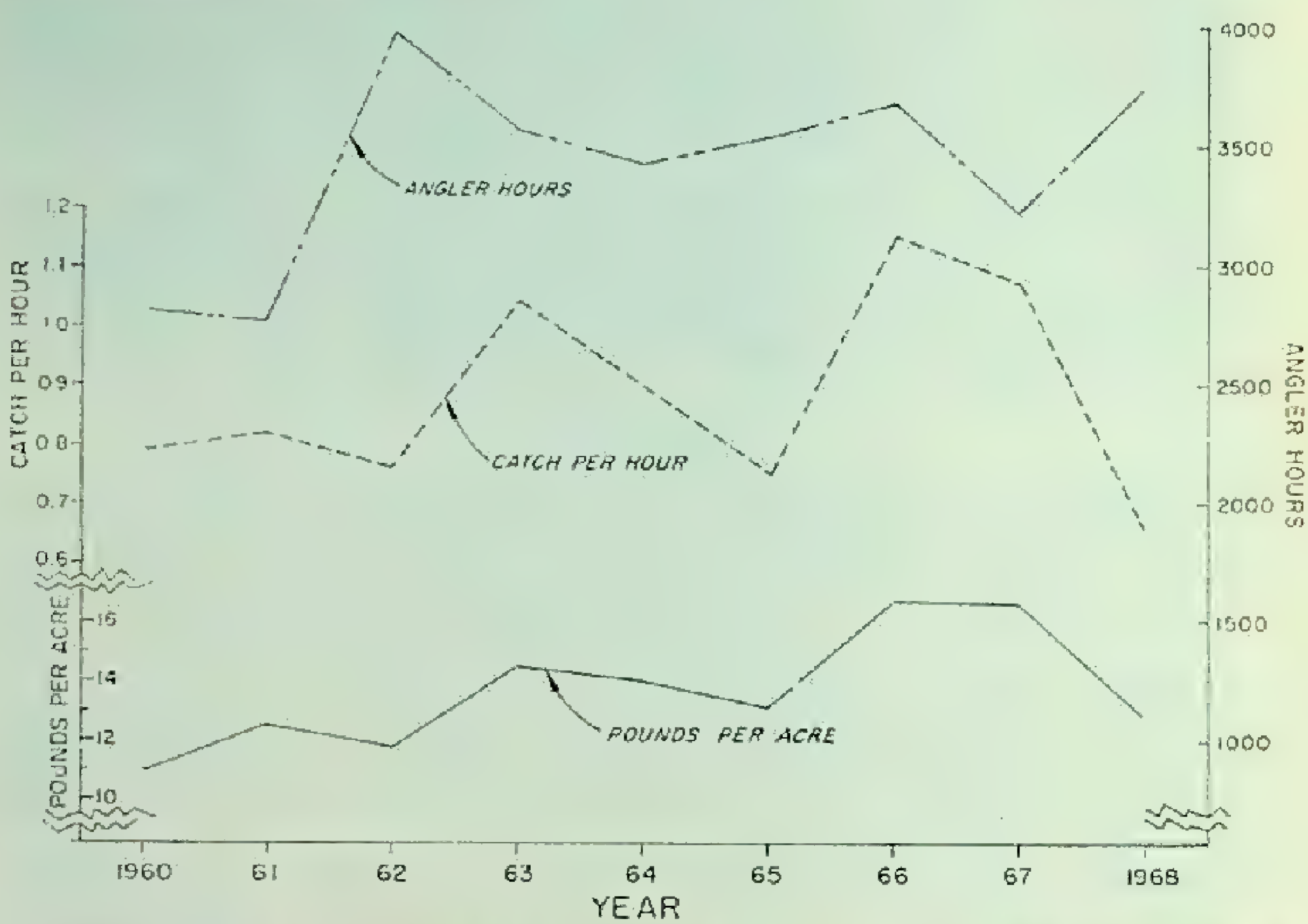

FIGURE 1—Estimated annual angler use and harvest of trout from Castle Lake, 1960–1968.

Total annual angler use varied from a low of 2,759 hr in 1961 to a high of 3,985 hr in 1962. From 1963 through 1968, however, use stabilized at about 3,500 hr (Table 1). Angler use was not correlated significantly with success rates nor with yields. Thus, increased angler use was not responsible for the record 1966–1967 yields and catch rates. Yields and success rates were, of course, strongly correlated ($r = 0.858$, d.f. $= 6$, $r_{.01} = 0.834$).

The 1966 and 1967 yields appear striking when compared with data collected before 1960. Although many different experiments were conducted during these years, fairly comparable yield data were obtained by eliminating catchable trout, since their weight represented growth in the hatchery. Both under a multiple species fishery (Wales, 1946) and when only eastern brook trout were found in the lake (Wales and

TABLE 1

Creel Census Data from Castle Lake, 1960–68

	1960	1961	1962	1963	1964	1965	1966	1967	1968
Fishing season days[1]	173	157	166	164	177	171	164	150	181
Number of angler days	920	852	1,213	1,377	1,438	1,409	1,359	1,198	1,681
Number angler hours	2,811	2,759	3,985	3,568	3,437	3,536	3,682	3,207	3,750
Mean hours fished per angler	3.1	3.2	3.3	2.6	2.4	2.5	2.7	2.7	2.2
Total catch	2,208	2,250	3,040	3,694	3,101	2,637	4,231	3,440	2,420
Mean catch per angler day	2.40	2.64	2.51	2.68	2.16	1.87	3.11	2.87	1.44
Mean catch per angler hour	0.79	0.82	0.76	1.04	0.90	0.75	1.15	1.07	0.65
Rainbow trout caught	1,824 (83%)	1,751 (78%)	2,085 (69%)	2,595 (70%)	1,971 (64%)	1,524 (58%)	3,109 (74%)	1,337 (39%)	1,108 (46%)
Eastern brook trout caught	384 (17%)	499 (22%)	955 (31%)	1,099 (30%)	1,130 (36%)	1,113 (42%)	1,122 (26%)	2,103 (61%)	1,312 (54%)
Pounds of rainbow trout caught	421.1 (80%)	462.0 (78%)	361.5 (64%)	463.6 (67%)	410.1 (61%)	335.8 (54%)	538.9 (67%)	322.7 (40%)	268.7 (44%)
Pounds of eastern brook trout caught	104.3 (20%)	133.7 (22%)	203.4 (36%)	230.3 (33%)	261.1 (39%)	287.2 (46%)	261.7 (33%)	474.1 (60%)	343.6 (54%)
Pounds of trout caught per surface acre	10.9	12.4	11.8	14.5	14.0	13.0	16.7	16.6	12.8
Mean weight (lb) of rainbow trout caught	0.24	0.26	0.17	0.18	0.21	0.22	0.17	0.24	0.24
Mean weight (lb) of eastern brook trout caught	0.27	0.27	0.21	0.21	0.23	0.26	0.24	0.22	0.26

[1] Trout fishing normally did not begin on the legal opening day, which is the Saturday nearest May 1, because of weather conditions. Thus, weather accounts for the principal variation in season days. In 1968 the season was lengthened to November 15; however, data for November are excluded from the 1968 figures.

German, 1956), the average yield was about 10 lb per acre. With a fishery based on wild eastern brook plus plants of fingerling rainbow, the average annual yield increased to 13 lb (Figure 2). According to Wales and Borgeson (1961), "The annual yield of Castle Lake from 1956 through 1959 ranged from 10.7 to 13.9 pounds per acre. The yields for 1958 and 1959 (12.8 and 12.9 pounds per acre, respectively) are believed to more closely approach the lake's potential under the brook trout-rainbow trout combination . . ." Thus, the 1966 and 1967 yields represent a significant increase in yield of about 3.5 lb per acre, or 168 lb for the entire lake.

Species Composition

Although the record yields in 1966 and 1967 were nearly identical, rainbow dominated the 1966 catch, while brook trout dominated the 1967 catch (Table 1, Figure 2). The yield of 11.2 lb of rainbow trout in 1966 was 32% higher than the 8.5-lb average for the 1960–1965 period, and the yield of 9.9 lb of eastern brook in 1967 was 125% greater than the 4.4-lb average for the years 1960 through 1966. The yield of rainbow in 1967 dropped to below the pre-1966 level, while the 1968 yield dropped even further. The latter decline was largely offset in 1968 by the eastern brook yield, which remained higher than normal. It is not possible to state whether this reversal in species dominance will continue. It does, however, represent a significant change in the catch composition from previous years (Table 1).

Eastern Brook Trout

Historically, the contribution of wild brook trout to the Castle Lake fishery reached a peak from 1952 through 1954, declined to a low level from 1958 through 1961, increased and then leveled off from 1962 through 1966, and finally attained another peak in 1967 and 1968 (Table 2). Wales and Borgeson (1961) believed that competition for food between brook and rainbow, and predation by rainbow on brook trout fry, were responsible for the decline of the brook trout population in Castle Lake. The relatively large plants of 15,000 rainbow in 1956 and 20,000 in 1958 may have accelerated the decline. The 1956 plant was probably of particular significance, since its survival rate was much higher than normal: 0.342 for fish age II and older compared with an average of 0.085 (range: 0.057 to 0.149) for the 1959 through 1965 plants. Stabilization of the rainbow planting density at 10,000 fish apparently led to the increase and subsequent stabilization of the brook trout population.

Monthly success rates for 1960 through 1963 were compared with those for 1964 through 1968 to demonstrate differences between the pre- and post-fertilization periods (Figure 3). Again the obvious change consisted of the unusually high 1967 brook trout catch rates. Angler success was higher during each month in 1967 than in comparable months in other years. Fishing success for brook trout generally peaks in May and June, declines to low levels in July, becomes virtually nonexistent in August, and then increases somewhat in September and October. Fishing success in 1967, however, was high in all months except August.

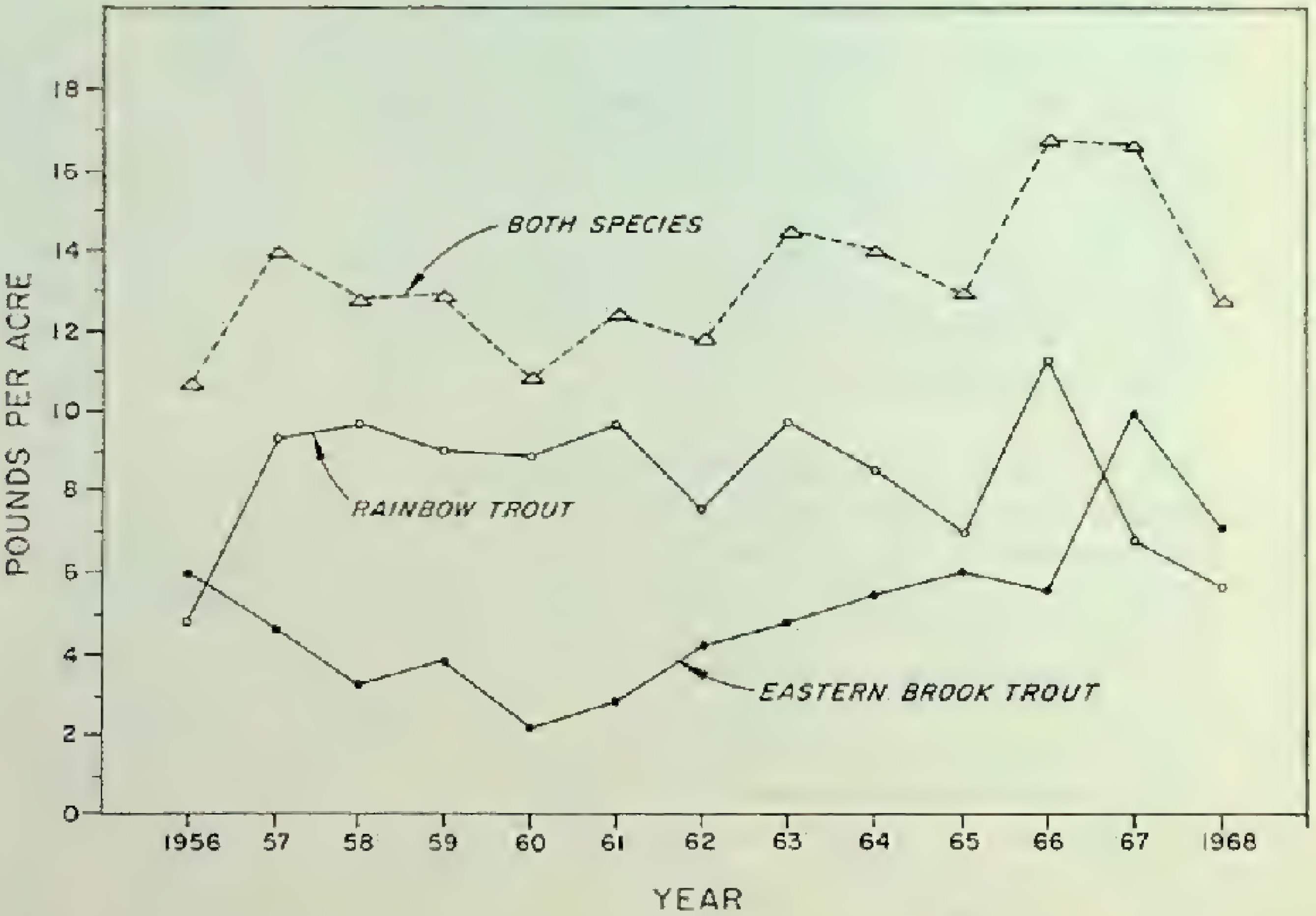

FIGURE 2—Estimated yield of rainbow and eastern brook trout from Castle Lake, 1956–1968.

TABLE 2

Catch, Yield, and Size of Eastern Brook Trout from Castle Lake, 1952–68 [1]

Year	Number caught	Catch per hour	Pounds caught	Yield (lb/acre)	Mean weight (lb)	Mean length (inches)
1968[2]	1,312	0.35	344	7.2	0.26	8.8
1967	2,103	0.66	474	9.9	0.22	8.3
1966	1,122	0.30	265	5.5	0.24	8.3
1965	1,113	0.31	287	6.0	0.26	8.6
1964	1,130	0.33	261	5.4	0.23	8.4
1963	1,099	0.31	230	4.8	0.21	8.2
1962	955	0.24	203	4.2	0.21	8.1
1961	499	0.18	134	2.8	0.27	8.6
1960	384	0.14	104	2.2	0.27	8.8
1959	776	0.29	184	3.8	0.24	8.5
1958	860	0.34	153	3.2	0.18	[3]
1957	1,277	0.25	220	4.6	0.17	[3]
1956	1,317	0.35	282	5.9	0.22	[3]
1955	1,470	[4]	295	6.1	0.20	[3]
1954	2,475	0.72	496	10.3	0.20	[3]
1953	1,828	0.38	350	7.3	0.19	[3]
1952	2,180	0.61	456	9.5	0.21	[3]

[1] All wild trout except for the following numbers planted as fingerlings in 1947 and 1948: 1952 — 836, 1953 — 256, 1954 — 119, 1955 — 21, 1956 — 14, 1958 — 3.

[2] Not including November 1968 data.

[3] Not determined.

[4] Data not comparable with other years because zero catches were not recorded for three months.

Growth rates of eastern brook trout were not analyzed. Monthly mean lengths, weights, and condition factors of angler-caught fish, however, were not significantly different before and after fertilization. An examination of annual length frequencies indicated that a strong year class, probably the 1965 year class, was responsible for the low mean lengths in 1966 and 1967 and the relatively high means in 1968 (Figure 4). This 1965 year class entered the creel at about 5 to 7 inches in 1966 and became fully recruited in 1967. Thus, it was most likely responsible for the high yield in 1967.

Rainbow Trout

Rainbow trout fingerlings have been planted annually since 1959 (Table 3). Although 10,000 fish were released each year at the same time, their condition and size at release varied from year to year.

The catch data are either complete or virtually complete for each plant of rainbow trout made from 1959 through 1965, and incomplete for 1966 and 1967. The harvests of these plants ranged from lows of 12% for the 1960 and 1964 plants to a high of 35% for the 1965 plant. The ultimate harvest of the 1966 plant probably will not exceed 12%.

The high 1966 rainbow yield, like the high 1967 brook trout yield, resulted from a strong year class. About 89% by number and 83% by weight of the rainbow caught in 1966 were age I fish from the 1965 plant. In the remaining eight years, age I fish comprised an average of 59% (range: 42 to 76%) by number and 45% (range: 25 to 63%) by weight.

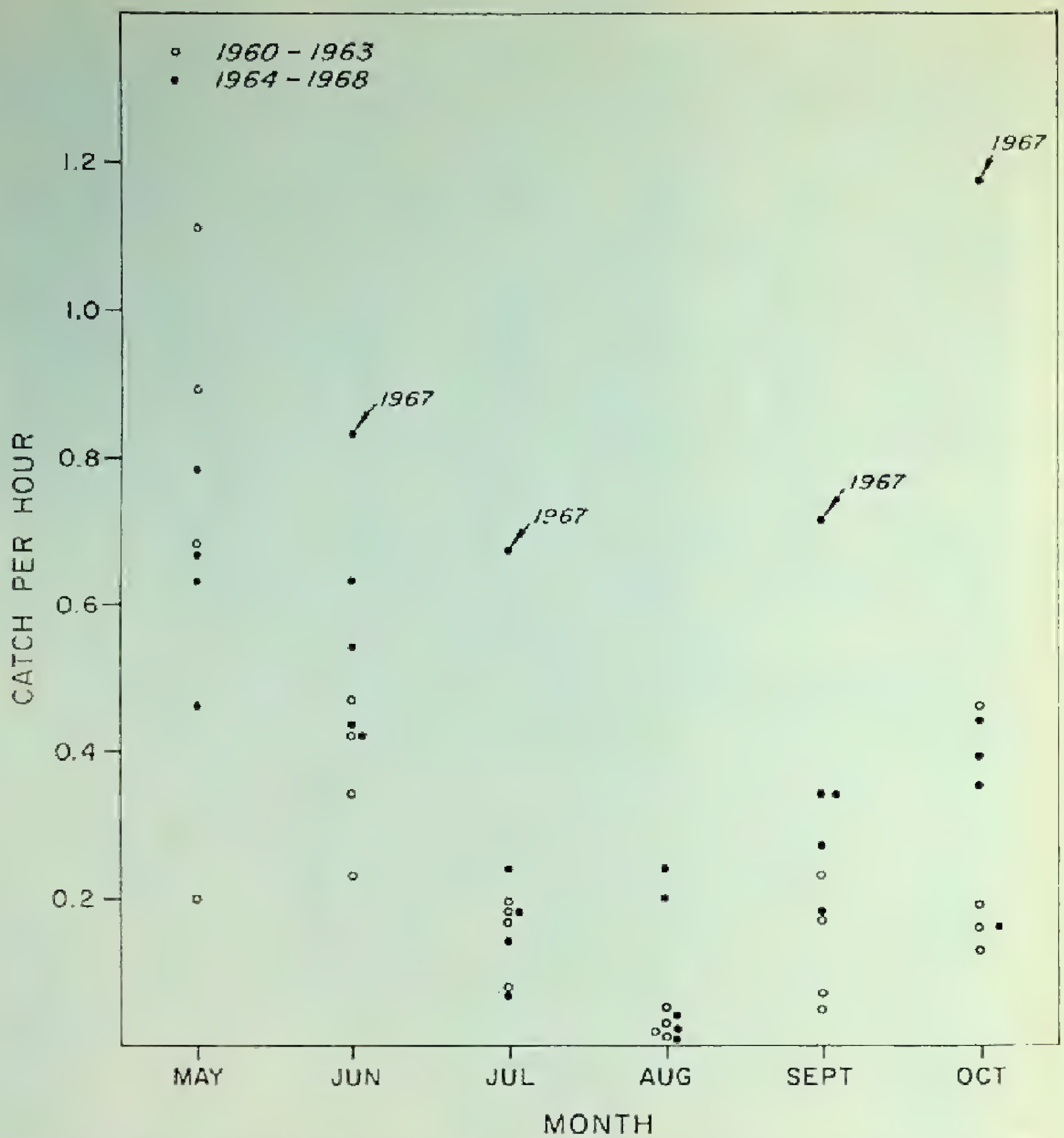

FIGURE 3—Monthly harvest rates of eastern brook trout from Castle Lake, 1960–1968. (No data for May 1967.)

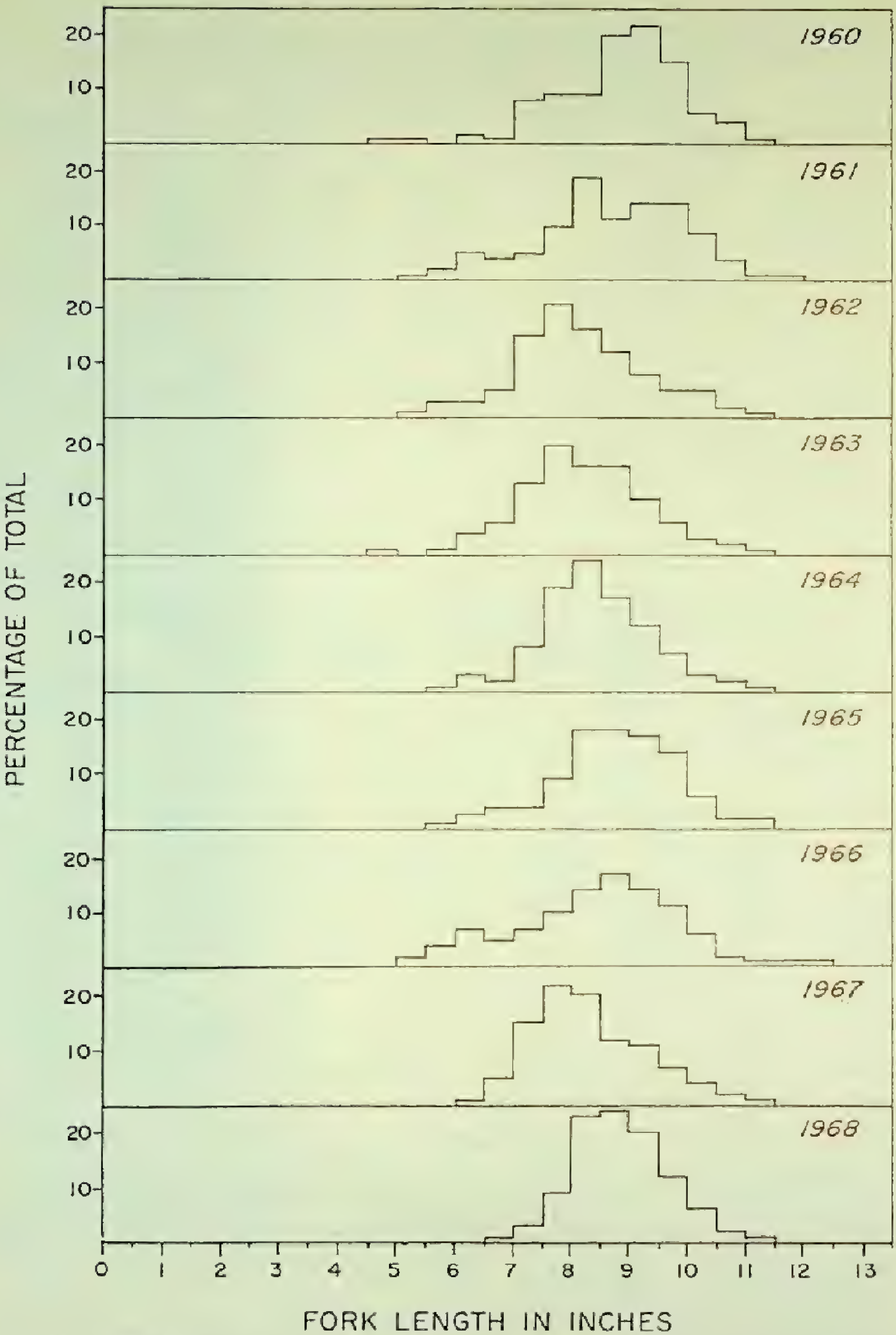

FIGURE 4—Length frequencies of angler-caught eastern brook trout from Castle Lake, 1960–1968.

TABLE 3

Total Catch of Planted Rainbow Trout from Castle Lake, 1959–67 [1]

Date planted	Size at release (no. /oz)	Observed loss	Number released alive	Mark[5]	Total catch	Percentage caught
Aug. 11, 1959	15.7	100	9,900	Ad-LV-RV	1,861	18.8[4]
Aug. 11, 1960	20.0	150	9,850	LP	1,135	11.5[4]
Aug. 11, 1961	11.0	20	10,287	RP	2,392	23.3[4]
Aug. 13, 1962	13.0	2	10,008	Ad	2,499	25.0[4]
Aug. 12, 1963	16.0	2	10,030	Ad-LV	1,770	17.6[4]
Aug. 26, 1964	15.0	10	9,980	Ad-RV	1,185	11.9[4]
Aug. 11, 1965[3]	9.0	0	10,008	RV	3,458	34.6[4]
Aug. 10, 1966[3]	7.5	10	9,990	LV	1,086	10.9[5]
Aug. 11, 1967[3]	20.0	150	9,850	[2]	639	6.5[5]

[1] All Shasta strain domestic rainbow trout reared at Mt. Shasta Hatchery under standard hatchery procedures.
[2] Divided into 7 groups of about 1,430 fish each: six marked D (dorsal), Ad (adipose), An (anal), RV (right ventral), RP (right pectoral), LP (left pectoral), plus an unmarked group.
[3] Returns for November 1968 not included.
[4] Returns complete or nearly so.
[5] Returns incomplete.

TABLE 4

Harvest of Rainbow Trout from Castle Lake, 1959–67, by Age Groups, as Percentage of Number Planted and (in Parentheses) Percentage of Total Catch of the Yearly Plant

Year planted	0	I	II	III	IV+	Total
1959	0.0	10.1	8.0	0.7	0.0	18.8[2]
	(0)	(51)	(43)	(4)	(0)	
1960	0.0	7.3	3.9	0.3	0.0	11.5[2]
	(0)	(64)	(34)	(2)	(0)	
1961	0.0	15.2	7.3	0.6	0.1	23.3[2]
	(0)	(65)	(32)	(3)	(0)	
1962	0.0	17.7	6.2	1.0	0.1	25.0[2]
	(0)	(71)	(25)	(4)	(0)	
1963	0.0	12.2	5.1	0.3	0.0	17.6[2]
	(0)	(69)	(29)	(2)	(0)	
1964	0.0	8.8	2.9	0.2	0.0	11.9[2]
	(0)	(74)	(24)	(2)	(0)	
1965[1]	0.1	27.6	6.1	0.7	--	34.6[2]
	(0)	(80)	(18)	(2)		
1966[1]	0.1	7.0	3.7	--	--	10.9[3]
1967[1]	0.0	6.5	--	--	--	6.5[3]

[1] Returns for November 1968 not included.
[2] Returns complete or nearly so.
[3] Returns incomplete.

Although the 1965 plant experienced relatively high survival during its first year in the lake, its contribution to the fishery at age II and older was not unlike that of the other plants (Table 4 and 5). This corresponded to a reduction in survival rate between age I and age II (Table 6).

In addition to the high return of age I rainbow in 1966, annual and monthly mean lengths for rainbow trout were somewhat higher for the post-fertilization years (Figure 5). The differences between pre- and post-fertilization years, however, were not statistically significant.

TABLE 5

Harvest of Rainbow Trout from Castle Lake, 1959–67, by Age Groups, as Pounds Harvested and (in Parentheses) Percentage of Total Pounds of Yearly Plant Caught

Year planted	0	I	II	III	IV+	Total
1959	0.0	163.8	249.9	27.4	0.5	441.6[2]
	(0)	(37)	(57)	(6)	(0)	
1960	0.0	113.7	88.1	8.4	2.0	212.2[2]
	(0)	(54)	(42)	(4)	(1)	
1961	0.3	224.3	182.6	25.3	3.8	436.3[2]
	(0)	(51)	(42)	(6)	(1)	
1962	0.0	261.2	168.4	48.1	3.3	481.0[2]
	(0)	(54)	(35)	(10)	(1)	
1963	0.0	200.8	140.4	14.1	1.0	356.3[2]
	(0)	(56)	(39)	(4)	(0)	
1964	0.0	138.7	73.5	6.9	0.7	219.8[2]
	(0)	(63)	(33)	(3)	(0)	
1965[1]	1.1	447.4	172.2	31.4	--	651.0[2]
	(0)	(69)	(26)	(5)		
1966[1]	1.0	141.9	121.7	--	--	263.6[3]
1967[1]	0.0	109.4	--	--	--	109.4[3]

[1] Returns for November 1968 not included.
[2] Returns complete or nearly so.
[3] Returns incomplete.

TABLE 6

Vital Statistics of Each Group of Rainbow Trout from Castle Lake, 1959–66

Year planted	Total fraction harvested	Age I to Age II			Age II and older		
		s	a	i	s	a	i
1959	0.188[2]	0.809	0.191	0.21	0.057	0.943	2.87
1960	0.115[2]	0.369	0.631	1.00	0.082	0.918	2.50
1961	0.233[2]	0.538	0.462	0.62	0.090	0.910	2.41
1962	0.250[2]	0.362	0.638	1.02	0.149	0.851	1.90
1963	0.176[2]	0.402	0.598	0.91	0.063	0.937	2.77
1964	0.119[2]	0.323	0.677	1.13	0.062	0.938	2.78
1965[1]	0.346[2]	0.256	0.744	1.36	0.093	0.907	2.38
1966[1]	0.109[3]	0.455	0.546	0.79	--	--	--

[1] Returns for November 1968 not included.
[2] Returns complete or nearly so.
[3] Returns incomplete.

DISCUSSION

The addition of molybdenum to Castle Lake in July 1963 probably caused the unusually high trout yields in 1966 and 1967. Goldman (1966) attributes significant increases in zooplankton in 1964 and 1965 to the molybdenum fertilization. Beatty (1968), who analyzed bottom fauna populations from 1963–1967, showed that there was an increase to record densities in 1965–1967. Although the increase may have been due to fertilization, he believed that it was possible that the increase might be the result of natural population fluctuations. In any case, increased standing crops of zooplankton and benthos probably resulted in greater survival of the 1965 year classes of rainbow and brook

trout. Such foods dominate the diet of trout in Castle Lake (Swift, 1970). These strong year classes comprised the bulk of the record yields of 1966 and 1967.

Factors other than fertilization, however, might have influenced to some degree the record harvests. As mentioned above, angler use from 1960 through 1968 was not correlated with corresponding values for

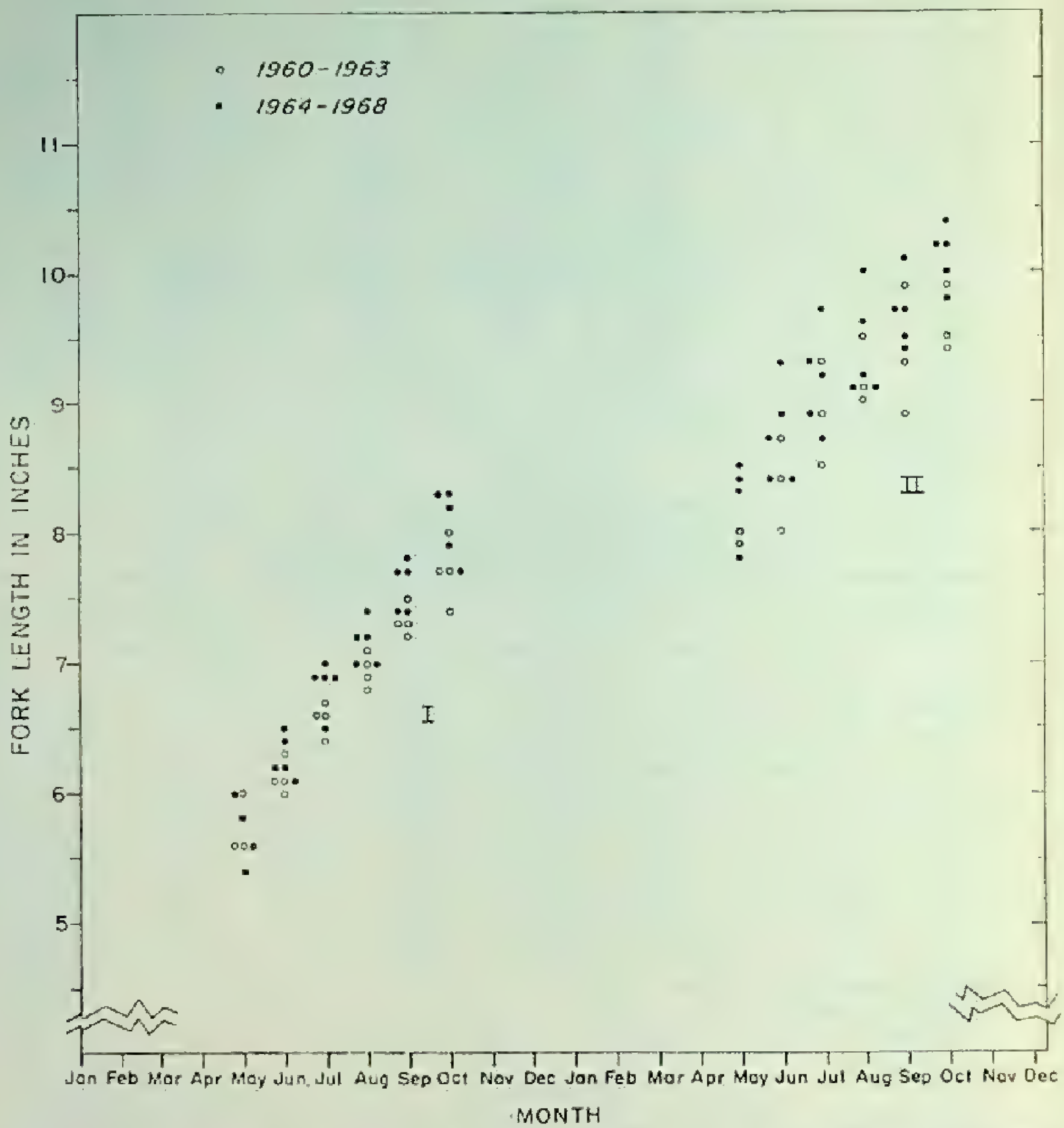

FIGURE 5—Monthly mean lengths of age I and II rainbow trout from Castle Lake, 1959–1967.

angler success and trout yield. Additional comparisons, between the harvest of each rainbow plant and total angler effort for the year following the plant and for the two years following the plant, revealed no significant relationships. Comparisons of the relative use and success of boat and shore anglers showed that boat anglers were much more successful than shore anglers. Monthly success rates for both rainbow and brook trout were higher for boat anglers than shore anglers

in 32 of 34 months for which data were available. Thus, a large increase in the proportion of boat to total anglers might alone boost yields. Although there was an increase in the proportion of boat angler use in recent years, it fell far short of significantly augmenting the 1966 and 1967 yields.

The size of trout at release apparently influences their survival (Table 3). For plants made from 1959 through 1965, there was a strong positive correlation between size at release and the ultimate percentage harvested ($r = 0.880$, d.f. $= 5$, $r_{.01} = 0.874$). However, if the 1966 plant is included, the correlation ceases to be significant. Although the rainbow stocked in 1966 were larger than those in any other plant, the return was poor. However, this may be the result of severe competition from survivors of the strong 1965 year class. Condition of the trout when released also may have influenced their survival. The data are very limited, but it should be noted that the only plant with no observed loss at release was the very successful 1965 plant.

It is possible that high survival of one year class of trout could depress survival of subsequent plants. Therefore, the harvest of a given plant was compared with the density of fish in Castle Lake at the time of release, using monthly mean catch per hour as an index of trout density. The fractions harvested of the 1966 through 1969 rainbow plants were not significantly correlated with the rainbow success rates for August of the same years, but there was a significant inverse correlation with the August through October catch rates ($r = -0.773$, d.f. $= 6$, $r_{.05} = 0.707$). Harvest was not correlated with combined rainbow and brook trout success rates from August through October. This was not unexpected, since the two species seem to be segregated from one another in Castle Lake, especially during the summer months (Swift, 1970). When the rainbow are released, brook trout are apparently closely associated with the substrate. At this time, surviving rainbow from earlier plants are distributed widely in the surface waters, where they probably compete directly with the stocked fingerlings.

Since the molybdenum addition led to a dramatic increase in zooplankton standing crop in 1964 (Goldman, 1966; Carlson, 1968), high survival of the 1964 rainbow plant might have been anticipated. On the contrary, this plant had one of the lowest harvest rates and yields (Tables 4 and 5). Based on numerous observations of fisheries managers and on unpublished data of the department's Coldwater Reservoir Study, trout fishing in California coldwater lakes and reservoirs tended to be unusually poor during the 1965 season. It is believed that runoff from an exceedingly heavy "tropical" storm during Christmas week of 1964 caused trout to move out of these waters. The Castle Lake area also suffered from this high intensity storm. Runoff records for the nearest stream gaging station representing unimpaired flows (Sacramento River near Shasta Lake) showed that the mean daily flow of 34,400 cfs on December 22, 1964, was the highest on record. A comparison of the harvest of each plant with the maximum daily flow for the water year (October through September) immediately following the plant demonstrated that the low survival of the 1964 plant was probably occasioned by loss of these fish during the December flood. A significant reduction in the 1964 rainbow population could then have

aided the establishment of the strong 1965 rainbow and brook trout year classes.

COST

The 35 lb of sodium molybdate added to Castle Lake cost $30. Application to the surface waters required such a minor expenditure of time and materials that costs related to application may be considered minimal.

If the observed increase in trout yield, which represents almost 350 lb for the two years, may be attributed solely to fertilization, then the cost per pound of the additional trout in the creel was less than $0.10. This compares favorably with rearing and planting costs for the rainbow fingerling stocking program at Castle Lake, which has averaged $0.35 per pound of trout in the creel.

CONCLUSION

Although it is possible that a fortuitous combination of favorable environmental factors led to the record high yields of trout from Castle Lake during 1966 and 1967, we believe there is a good possibility that artificial enrichment with molybdenum was the primary factor. If this is true, the addition of small amounts of limiting trace elements to high mountain lakes would be a management tool of great significance. A second addition of molybdenum to Castle Lake was made in June 1969, and continued and improved measures of biological variables are planned to help verify results of the first experiment.

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A QUALITATIVE AND QUANTITATIVE STUDY OF TROUT FOOD IN CASTLE LAKE, CALIFORNIA[1]

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Trout in Castle Lake were studied, using stomach content analysis and calorimetry, to delineate their diets and energy supply. A qualitative difference exists between foods of the eastern brook trout, *Salvelinus fontinalis*, and rainbow trout, *Salmo gairdnerii*, with the brook trout feeding primarily on benthic organisms and the rainbow trout feeding primarily on terrestrial organisms. Zooplankton is eaten equally by both species. Based on the energy content of the food items and their proportions in the diet, 40% of the total energy consumed by the trout is benthic in origin, about 10% is pelagic, and about 50% is terrestrial.

INTRODUCTION

Despite advances in trout management, one cannot predict with certainty how a fish population will adapt to its environment. Successful management of fish populations requires a sound knowledge of food availability and utilization. The examination of stomach contents provides a means of studying both these parameters.

This study was carried out at Castle Lake, California, with populations of eastern brook and rainbow trout. The objectives of the study were (i) to determine what organisms made up the trout diet, (ii) to determine the caloric value of each food item, and (iii) to calculate the relative importance of each food item in the diet of the two trout populations.

STUDY AREA

Castle Lake is located about 10 miles southwest of the city of Mount Shasta in Siskiyou County, California. It is a cirque lake bounded by steep cliffs on the south, by high ridges on the east and west, and by a terminal moraine on the north. It is fed by snowmelt in the spring and by underwater springs throughout the year. The single outflow is through the moraine at the north end. The lake lies at an elevation of 1,707 m (5,600 ft) and has an area of 20.1 ha (49.6 acres). The northern half of the lake averages about 3 m in depth and the southern end drops steeply to 37 m. Ice covers the lake from December to mid-April or May. Strong thermal statification occurs in the summer, with the thermocline usually at about 9 meters. Surface temperatures in August reach 22 C. The lake has a self-sustaining population of brook trout; rainbow trout, which do not reproduce in the lake, are maintained by an August plant of 10,000 fingerlings. The Castle Lake fishery has been studied since 1938 by the California Department of Fish and Game (Wales, 1946; Wales and German, 1950, 1956; Wales and Borgeson, 1961). Limnological studies were begun in 1959 and

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TABLE 1

Food of Eastern Brook Trout in Castle Lake, Averages for 1963, 1964, and 1965 *

	May			June			July			August			September			October		
	N	V	P	N	V	P	N	V	P	N	V	P	N	V	P	N	V	P
Aquatic organisms																		
Odonata																		
Dragonfly n.	188	64.3	**33.0**	66	17.3	**14.6**	9	2.8	**9.6**	3	0.5	**11.6**	44	18	**30.2**	19	11.7	**53.8**
Damselfly n.	33	9.0	**5.0**	6	1.5	**1.4**	1	1.0	**0.6**	--	--	--	0.7	Tr	**0.1**	2	0.4	**2.3**
Ephemeroptera																		
Mayfly n.	2	0.2	**0.1**	--	--	--	6	0.2	**0.5**	--	--	--	--	--	--	1	0.5	**0.4**
Trichoptera																		
Caddisfly l.	86	9.0	**4.0**	206	16.0	**14.9**	30	1.4	**3.3**	4	0.05	**0.2**	9	0.6	**0.7**	13	1.2	**4.4**
Diptera																		
Chironomidae	130	1.5	**0.7**	1500	6.1	**6.4**	424	3.1	**10.3**	16	0.1	**2.5**	153	1.1	**1.8**	1.3	Tr	Tr
Heleidae p.	--	--	--	1331	3.0	**2.7**	--	--	--	--	--	--	--	--	--	--	--	--
Heleidae l.	21	0.1	**0.1**	350	7.5	**2.6**	7	0.2	**0.4**	33	0.3	**1.6**	--	--	-	--	--	--
Neuroptera																		
Sialidae	4	2.0	**1.2**	2	0.6	**0.4**	0.3	Tr	Tr	--	--	--	--	--	--	--	--	--
Acarina																		
Water mites	--	--	--	1	Tr	Tr	--	--	--	--	--	--	--	--	--	--	--	--
Cladocera																		
Daphnia	400	0.3	**0.1**	4389	11.4	**9.6**	737	3.1	**8.4**	1415	5.7	**52.7**	2227	12.1	**18.0**	461	1.8	**9.2**
Eurycercus	--	--	--	--	--	--	24	0.8	**0.3**	242	0.8	**4.8**	74	0.2	**0.3**	308	0.9	**3.2**
Oligochaeta	--	--	--	1	Tr	Tr	--	--	--	--	--	--	--	--	--	--	--	--
Mollusca																		
Snails	12	1.0	**0.4**	16	1.6	**1.2**	6	0.7	**3.2**	3.3	0.2	**8.6**	4	0.2	**0.2**	3.7	0.2	**1.0**
Clams	8	0.4	**0.2**	16	0.6	**0.4**	1	Tr	Tr	2.7	Tr	**0.2**	0.7	Tr	Tr	0.7	0.7	**1.3**

Terrestrial organisms																		
Diptera	1.3	Tr	Tr	24	1.1	1.0	22	1.7	4.8	--	--	--	1.3	Tr	Tr	--	--	--
Hymenoptera																		
Ants	--	--	--	--	--	--	--	--	--	0.3	Tr	1.0	282	8.6	9.1	--	--	--
Others	21	2.4	0.9	15	0.2	0.3	0.3	Tr	Tr	--	--	--	--	--	--	0.3	Tr	Tr
Coleoptera	17	1.8	0.8	3	0.2	0.1	0.6	Tr	0.2	--	--	--	--	--	--	--	--	--
Neuroptera	--	--	--	--	--	--	0.3	0.2	0.6	--	--	--	--	--	--	--	--	--
Homoptera	42	0.1	Tr	11	0.1	0.1	7	0.5	1.3	--	--	--	8	0.4	0.7	--	--	--
Hemiptera	0.3	0.1	0.1	52	0.6	0.8	--	--	--	--	--	--	1.3	Tr	Tr	--	--	--
Lepidoptera	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Odonata																		
Damselflies	--	--	--	--	--	--	2	1.0	2.0	--	--	--	--	--	--	--	--	--
Arachnida	--	--	--	8.7	0.1	0.1	--	--	--	--	--	--	--	--	--	--	Tr	--
Frog	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.3	4.3	Tr
Worms	--	0.3	0.2	--	1.2	0.8	--	0.5	2.0	--	0.2	0.8	--	--	--	--	--	26.6
Debris and unidentifiable material	--	38.5	19.2	--	41.7	40.1	--	15.7	42.4	--	0.5	16.3	--	25.5	37.7	--	--	--
Total volume		133.2			106.8			33.8			8.4			67.3			20.6	
Number of stomachs		74			43			18			3			21			16	

* N = number, V = volume (ml), P = % of the total volume, Tr = less than 0.05 (ml or %), l = larvae, n = nymphs, p = pupae.

TABLE 2

Food of Rainbow Trout in Castle Lake, Averages for 1963, 1964, and 1965 *

	May (1963, 1964)			June			July			August			September			October		
	N	V	P	N	V	P	N	V	P	N	V	P	N	V	P	N	V	P
Aquatic organisms																		
Odonata																		
Dragonfly n.	32	12.7	**10.0**	0.3	0.2	**0.1**	16	10.7	**10.7**	20	12.3	**11.5**	23	14.3	**6.6**	4	4.0	**5.6**
Damselfly n.	0.7	0.1	**0.1**	0	1.6	**0.9**	0.7	Tr	**0.1**	6	1.0	**1.1**	22	1.3	**0.8**	4	0.7	**1.1**
Ephemeroptera																		
Mayfly n.	2.7	0.1	**0.1**	4	0.4	**0.7**	28	0.1	**0.4**	1	0.2	Tr	11	0.2	**0.1**	4	Tr	Tr
Plecoptera																		
Stonefly n.	--	--	--	--	--	--	--	--	--	--	--	--	12	0.2	Tr	--	--	--
Trichoptera																		
Caddisfly l.	72	5.2	**4.5**	47	4.0	**5.0**	26	2.0	**2.7**	18	0.1	**0.1**	26	1.8	**0.7**	58	4.2	**2.0**
Diptera																		
Chironomidae	156	1.6	**1.2**	324	3.0	**2.6**	253	2.1	**1.9**	122	0.5	**0.9**	2224	9.2	**2.6**	13	0.1	**0.1**
Heleidae p.	--	--	--	5577	14.2	**7.4**	23	0.1	**0.1**	--	--	--	--	--	--	--	--	--
Heleidae l.	134	0.7	**1.5**	502	3.3	**3.0**	4.7	Tr	Tr	9	0.1	**0.1**	25	0.2	**0.1**	--	--	--
Neuroptera																		
Sialidae	--	--	--	--	--	--	--	--	--	--	--	--	0.3	0.1	Tr	--	--	--
Cladocera																		
Daphnia	1583	6.3	**3.9**	4666	13.4	**10.5**	2154	8.9	**8.4**	5346	22.0	**26.1**	17367	75.0	**24.5**	20944	51.6	**29.3**
Eurycercus	--	--	--	--	--	--	81	0.3	**0.3**	37	0.3	**0.2**	537	2.0	**0.4**	352	1.0	**0.7**
Oligochaeta	65	0.6	**0.4**	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Copepoda	--	--	--	--	--	--	2	Tr	Tr	--	--	--	--	--	--	--	--	--
Mollusca																		
Snail	2	Tr	Tr	6	0.4	**0.2**	2.3	0.2	**0.2**	7	0.1	**0.1**	21	0.4	**0.1**	12	0.2	**0.2**
Clam	3	0.4	**0.4**	1	Tr	**0.1**	--	--	--	--	--	--	--	--	--	32	0.4	**0.1**
Fish	0.3	0.3	**0.4**	--	--	--	0.3	0.2	Tr	0.3	0.7	**0.8**	--	--	--	0.3	0.8	**0.3**

Terrestrial organisms																		
Diptera	71	4.4	5.4	61	3.8	1.9	88	3.0	2.7	58	2.5	2.6	173	2.2	4.3	204	5.7	5.0
Hymenoptera																		
Ants	--	--	--	3	2.0	3.0	18	0.6	0.5	175	8.0	7.0	2041	70.2	21.0	119	9.2	4.2
Others	61	6.3	4.2	52.3	10.1	4.8	37	1.8	1.6	12	3.0	3.3	9	1.0	0.6	206	6.6	4.3
Coleoptera	42.9	2.0	1.8	48	3.8	2.7	55	5.0	4.4	38	1.4	1.4	4	0.4	0.2	41	1.7	1.0
Neuroptera	--	--	--	--	--	--	0.3	Tr	Tr	1	0.1	0.3	0.3	Tr	Tr	--	--	--
Homoptera	51	0.9	0.7	10	2.2	1.0	36	2.5	2.2	6	0.4	0.5	134	2.3	0.6	122	4.3	2.7
Hemiptera	2	0.4	0.5	8	0.1	0.2	2	0.1	0.1	209	2.5	4.6	1481	12.8	4.3	126	2.3	1.6
Lepidoptera	--	--	--	--	--	--	--	--	--	--	--	--	0.3	Tr	Tr	--	--	--
Odonata																		
Dragonflies	--	--	--	--	--	--	0.7	0.7	0.6	--	--	--	--	--	--	--	--	--
Damselflies	--	--	--	--	--	--	10.3	4.7	4.1	--	--	--	2	0.6	0.5	5	4.0	1.4
Orthoptera																		
Acrididae	--	--	--	--	--	--	0.3	0.7	0.6	--	--	--	--	--	--	0.3	0.3	0.2
Arachnida	8	0.1	0.1	14	0.3	0.3	11	0.2	0.1	7	0.3	0.4	1	Tr	Tr	64	1.5	0.7
Salmon eggs	--	--	--	20	10.0	4.4	22	13.3	18.2	15	10.3	4.7	0.3	0.1	Tr	0.7	2.0	0.1
Worms	--	--	--	--	--	--	--	1.0	1.6	--	4.0	2.9	--	2.0	0.8	--	0.8	0.5
Debris and unidentifiable material	--	39.5	31.8	--	80.4	55.7	--	36.4	36.0	--	25.1	31.8	--	78.9	34.1	--	63.9	33.3
Total volume		85.0			149.9			97.3			88.9			267.4			159.8	
Number of stomachs		27			45			38			26			67			72	

* N = number, V = volume (ml), P = % of the total volume, Tr = less than 0.05 (ml or %), l = larvae, n = nymphs, p = pupae.

have continued on a year-round basis. They include nutrient limiting factors and primary productivity (Goldman, 1960, 1963, 1967), zooplankton population dynamics (Carlson, 1968), and benthos communities (Beatty, 1968).

METHODS AND MATERIALS

All stomachs examined were from fish caught by anglers at Castle Lake. Samples from the 1963, 1964, and 1965 fishing seasons were collected and preserved in formalin following the method of Borgeson (1963). These samples were pooled by fish species each month. Samples taken during the summer of 1966 and winter of 1966–67 were preserved in formalin until counted. From May 1967 to May 1968 the whole stomach was taken and frozen before counting. Individual food items were picked out of these samples and dried at 50 C at least 48 hr for calorimetric determination. During the winter, fish were taken through the ice using a handline. Rainbow trout stomachs were sampled by year class (I, II, III, IV) using a fin clip code. The brook trout stomachs were sampled according to arbitrary size classes (<6, 6–8, 8–10, >10 inches).

Food items were counted in a petri dish using a 10X binocular dissecting microscope. For the 1966 samples, number and frequency of occurrence were recorded, while number and volume were measured for each food item during 1967–68. Volumes were determined by water displacement in a graduated centrifuge tube. The 1963–65 samples were counted using the method of Borgeson (1963) to obtain number and volume.

Caloric values were determined using a nonadiabatic Phillipson microbomb calorimeter calibrated with benzoic acid. Individual food items, keyed to family or genus, were pooled from several samples, dried, pulverized, made into pellets, and combusted. Five determinations were made for each food item and the mean taken as the caloric value.

For convenience, the various stomach contents were divided into four categories: terrestrial food, pelagic food, benthic food, and debris or unidentifiable material. Terrestrial food included any food item originating outside the lake. Pelagic food included the zooplankton (*Daphnia*, *Holopedium*, and *Diaptomus*) and fish. The benthic component included those organisms that spend the majority of their time on the bottom of the lake. This included the permanent bottom dwellers (snails, clams, and oligochaetes) and the transient population of juvenile aquatic insects. Debris included cigarette filters, rocks, insect wings, pine needles, etc. These categories were chosen to show the source of the trout food. Aquatic nymphs and larvae were considered to be benthic in origin, although they may often be found in the pelagic zone or at the surface.

RESULTS

Insects, both terrestrial and aquatic, were the major part of the food eaten by both brook and rainbow trout throughout the year (Tables 1 and 2). Zooplankton was a moderately important food item for brook trout, but made up a larger proportion of the rainbow trout food. *Daphnia rosea* was the major zooplankter eaten by both species.

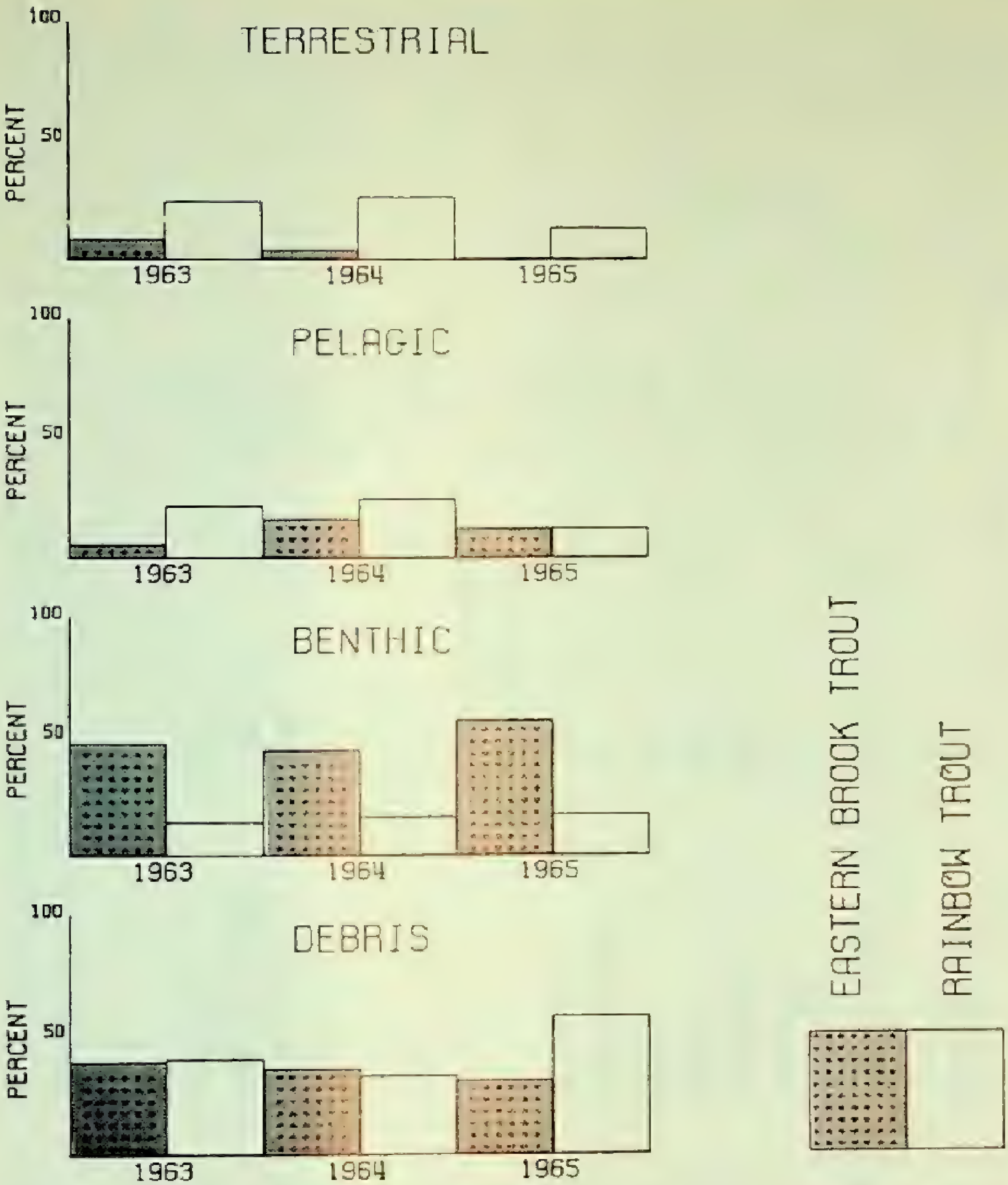

FIGURE 1—Food of eastern brook and rainbow trout in Castle Lake; percentage of the total volume of stomach contents by category, 1963, 1964, and 1965.

Rainbow and brook trout less than 5 inches were not adequately sampled. However, stomachs of fingerling rainbow trout taken after planting in 1964, 1966, and 1967 contained small terrestrial insects and cladocerans. Occasional small rainbow trout caught in the winter contained copepods (probably *Diaptomus novamexicanus*). No data on the food of brook trout fry and fingerlings are available.

Brook trout and rainbow trout had different diets (Figure 1). Rainbow trout ate three times more terrestrial food than brook trout, while brook trout ate three times more benthic food than rainbow trout. Pelagic food was about evenly split between the two species, while debris formed a relatively constant 40 to 60% of the stomach contents. The

same data were analyzed on a monthly basis (Figure 2). Pelagic food reached its maximum during the late summer when the *Daphnia* population was at its peak. Both rainbow and brook trout fed on zooplankton during this period.

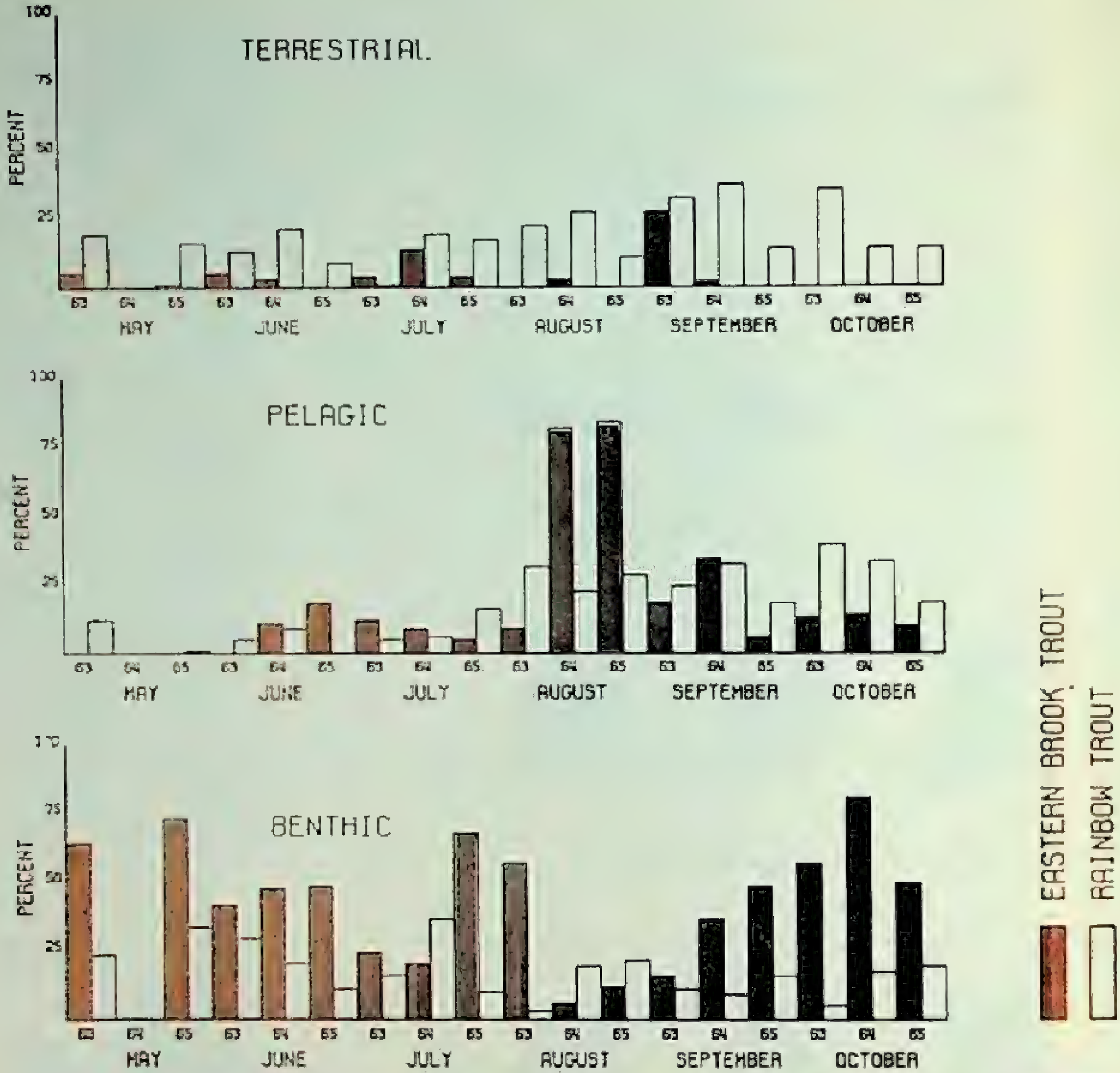

FIGURE 2—Food of eastern brook and rainbow trout in Castle Lake; percentage of the total volume of food items by category and month, 1963, 1964, and 1965.

Sampling during the winter months of 1967–68 showed that after the lake froze, benthos comprised virtually 100% of the food of both eastern brook and rainbow trout. When the lake thawed in May, terrestrial food was again utilized.

The relative value of each food item as an energy source was determined from calorimetric data and is expressed as the number of each food item required to produce 1,000 calories (Table 3). Dragonfly nymphs, *Sialis* larvae, Coleoptera, ants, and damselfly nymphs are clearly the most energy-rich foods. The energy provided to the fish by each food item (Table 4) was estimated using stomach content data for 1963, 1964, and 1965 (Tables 1 and 2) and the energy available per food item (Table 3). Dragonfly nymphs (61.6%), ants (11.3%),

Daphnia (10.0%), and chironomid larvae (8.2%) accounted for 91.1% of the total calories eaten by brook trout. Ants (42.8%), *Daphnia* (25.6%), beetles (11.1%), and dragonfly nymphs (8.1%) made up 87.6% of the total calories eaten by rainbow trout. Grouping these data into the three food categories showed brook trout energy intake to be 75.9% benthic, 14.1% terrestrial, and 10.0% pelagic. For the rainbow trout 55.9% was terrestrial, 25.6% was pelagic, and 18.5% was benthic. For the two trout populations, the benthos provided 36.3% of the total energy consumed, 20.7% was from pelagic food, and 48.2% was from terrestrial food.

TABLE 3

Energy Content of Some Food Items of Trout in Castle Lake

	Calories per gram of ash-free dry weight*	Number · 1000 cal^{-1}
Dragonfly nymphs	5514 ± 285	15
Sialis larvae	5928 ± 225	17
Coleoptera	5738 ± 596	26
Hymenoptera: ants	5898 ± 319	70
Damselfly nymphs	5374 ± 125	85
Homoptera	5494 ± 303	623
Diptera	4989 ± 789	677
Chironomid larvae and pupae	5542 ± 104	759
Caddisfly larvae	4409 ± 871	1000
Heleidae larvae	5708 ± 271	1481
Heleidae pupae	5508 ± 463	1966
Cladocera (*Daphnia*)	5272 ± 149	2586
Clams (without shell)	--	2925
Clams (with shell)	3787 ± 367	367
Hymenoptera	5320 ± 207	207
Hemiptera	5771 ± 100	100
Snails	3484 ± 229	229

* Shown with 95% confidence limits.

TABLE 4

Energy and Percentage of the Total Energy in Food Consumed by Trout in Castle Lake, 1963–65 *

	Eastern brook trout			Rainbow trout		
	N	Cal	%	N	Cal	%
Dragonfly nymphs	329	22000	61.6	96	6400	8.1
Sialis larvae	6	353	1.0	1	59	0.1
Coleoptera	21	808	2.3	228	8769	11.1
Hymenoptera: ants	823	4043	11.3	2356	33657	42.8
Damselfly nymphs	43	506	1.4	43	506	0.6
Homoptera	71	114	0.3	368	591	0.8
Diptera	48	71	0.2	655	968	1.2
Chironomid larvae	2225	2931	8.2	3092	4074	5.2
Caddisfly larvae	348	348	1.0	247	247	0.3
Heleidae larvae	411	278	0.8	675	456	0.6
Heleidae pupae	1334	679	1.9	5600	2848	3.6
Clams	30	10	Tr	36	12	Tr
Daphnia	9632	3572	10.0	52060	20131	25.6

* N = number eaten, Cal = calories eaten, % = percentage of the total calories eaten, Tr = less than 0.05%.

Utilization of the available benthos by fish was computed using Beatty's (1968) data on benthic standing crop for 45 months from 1963 through 1967, and the 1963–65 stomach content data (Table 5). Chironomid larvae contained most (83.8%) of the benthic energy but only a small fraction of their potential energy was consumed (5.8%). Caddisfly larvae (37.1%), dragonfly nymphs (59.8%), and damselfly nymphs (33.5%) were the benthic food items eaten most by trout in Castle Lake.

TABLE 5

Total Energy in Seven Selected Benthic Food Items and Their Utilization by Trout in Castle Lake

	Percentage of total benthic energy	Percentage utilization by fish
Chironomid larvae	83.8	5.8
Heleidae larvae	6.9	1.8
Heleidae larvae and pupae	7.9	10.1
Clams (without shell)	0.1	3.3
Caddisfly larvae	0.3	37.1
Dragonfly nymphs	8.2	59.8
Damselfly nymphs	0.5	33.5

DISCUSSION

Studies of brook trout diet have shown that aquatic insect larvae are the primary food source throughout the year. Lord (1933) found that by volume aquatic food ranged from 38% in summer to 98% during winter in a Vermont stream. Results reported here show similar percentages (Table 1). Although rainbow trout also fed primarily on insects, most of their food was terrestrial rather than benthic. Wales (1946) showed that benthic food decreased in importance as rainbow trout got older. Rainbow trout fed more regularly and on a wider variety of organisms than brook trout (Tables 1 and 2). This apparently is due to their extensive use of the terrestrial food source.

Although sparse, data on the food of fingerling rainbow trout suggest that zooplankton makes up a large proportion of the food of these fish. Cladocerans are probably most important in the summer, while copepods might be more important in the winter.

Nilsson (1963, 1965, 1966) demonstrated that sympatric fish species are often found in a more restricted habitat than allopatric species and that this interactive segregation is reflected in their food habits. This, I believe, is the case in Castle Lake. The presence of rainbow trout and the tendency of the brook trout to avoid the high summer water temperatures (22 C) caused the brook trout population to be displaced to the lower strata of the lake. This allowed the rainbow trout to exploit the surface waters and terrestrial food. When brook trout existed alone in Castle Lake, an average of 46%, by volume, of their food was terrestrial (Wales and German, 1950). During this study, terrestrial food exceeded 25% of the total volume of brook trout food only during September 1963.

The amount of energy available and eaten is of primary importance to any fish population. It is evident that a few food items are providing the bulk of the energy eaten by each species (Table 4). Four food

items account for 91% of the total calories eaten by brook trout and for 88% of the calories eaten by rainbow trout.

There is a large discrepancy between the energy present in the benthos in Castle Lake and the benthic energy actually consumed (Table 5). Since food utilization is directly related to its availability, it is clear that most of the potential energy represented by benthos is unavailable to the fish. Because chironomid larvae live below the flocculent mud-water interface, they are less subject to predation than are the dragonfly and damselfly nymphs and the caddisfly larvae, which live on aquatic vegetation and rocks. Accordingly, they are eaten less by the fish than are the more exposed nymphs and larvae. The high percentage utilization for Heleidae (larvae and pupae) is due to predation on the pupal stage, which is seldom found in the mud (K. Beatty, College of the Siskiyous, pers. comm.).

An apparent solution to the problem of increasing the energy consumption of fish is to manipulate the food supply either by fertilization or by the addition of new food items. Fertilization with micronutrients is currently being investigated in Castle Lake. Manipulation of the food chain, however, might lead to a reduction in available energy rather than in an increase if it is done without a thorough knowledge of the system in question. This method, however, would seem to hold the most promise for increasing fish yield, in spite of its difficulties.

ACKNOWLEDGMENTS

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BIOASSAY OF KING SALMON EGGS AND SAC FRY IN COPPER SOLUTIONS[1]

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Flowing water bioassay of king (chinook) salmon (*Oncorhynchus tshawytscha*) eggs and fry in a copper solution indicated that eggs are more resistant to the toxic effects of copper than fry. Copper concentrations of 0.08 mg/liter did not noticeably affect the hatching success of eyed eggs, but concentrations as great as 0.04 mg/liter were acutely toxic to fry and concentrations of 0.02 mg/liter caused increased mortality and inhibited growth.

INTRODUCTION

In a few California streams copper, among other heavy metals, represents a danger to salmonid fisheries. A case in point results from the flow of Spring Creek into the Sacramento River near Redding, immediately above a major spawning and nursery area (Prokopovich, 1965). Fish kills in this reach of the Sacramento occur with some regularity and predictability. Partially successful attempts have been made by the U. S. Bureau of Reclamation to maintain copper concentrations below a level acutely toxic to fish by regulation of flows from Shasta Dam and Spring Creek Debris Dam. Dilution flows are computed from criteria for acute toxicity based on susceptibility of king salmon fry and fingerlings to copper (Lewis, 1963). Low concentrations of heavy metals occur in this area, especially during winter and spring. Except for instances when concentrations become great enough to cause noticeable fish kills, the effects of copper and other heavy metals on this part of the river are undefined. Because little was known about the effects of copper on king salmon eggs and yolk-sac fry, experiments were run to gather such information. This information may be used as a base from which to estimate whether copper concentrations are great enough in the interstices of spawning gravels to affect fish production.

MATERIALS AND METHODS

Flowing water bioassay experiments were carried out using king salmon eggs and fry in the yolk-sac stage. Two batches of eggs from individual females were obtained from Coleman National Fish Hatchery on March 19, 1969, and April 18, 1969. The first batch was spawned and transported to the Department's Water Pollution Control Laboratory at Nimbus on the American River near Sacramento in a green state and used in an initial bioassay. Because of problems encountered in handling green eggs and operation of experimental apparatus, the

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first test was ended prematurely. Eyed eggs (25 days old) were obtained from the hatchery and used in the second test.

Experiments were performed in a flowing water bioassay apparatus designed and constructed at the laboratory. Regulation of flows was by constant head tanks, and an acidified solution of $CuSO_4 \cdot 5H_2O$ was continuously injected at three different rates into filtered American River water. Concentrations of copper ion in the test solutions were measured by atomic absorption analysis on samples collected and immediately filtered through a type HA Millipore filter. After filtration, samples were acidified with hydrochloric acid to a pH of 2 to 3. Test solutions had a pH from 6.8 to 7.2 and alkalinity and hardness of 21 and 44 mg/liter $CaCO_3$, respectively. Water temperatures during the experiments were between 13 and 14 C. Dissolved oxygen was near saturation.

Initially, the strength of copper solutions was estimated by measurement of flows in the bioassay apparatus. That is, by selection of a stock solution, it was arranged so that the test solutions should have contained 0.000 (control). 0.021 (low), 0.056 (medium), and 0.100 (high) mg/liter copper. Slightly different values were obtained by measurement of Rhodamine-B dye and copper in the test solutions (Table 1). Dye and flow measurements were conducted in a separate test. Dye concentrations were measured with a Turner Model III fluorometer, and copper was measured with a Beckman atomic adsorption spectrophotometer. The values derived by three different methods of calibration of the bioassay apparatus are relatively close. The best correspondence was between dye and copper rather than between flow and dye or copper.

TABLE 1

Percentage and Concentration in Mg/Liter of Toxicant in Test Solutions as Estimated by Measurement of Rate of Flow, Dye, and Copper

	Control	Test solution concentration		
		Low	Medium	High
Flow	0	5.90 (0.013)[1]	16.59 (0.036)	29.44 (0.063)
Dye	0	7.42 (0.016)	19.86 (0.043)	35.53 (0.077)
Copper	0	9.72 (0.021)	18.52 (0.040)	37.04 (0.080)

[1] Values in parentheses are computed concentrations of copper in mg/liter using a stock toxicant of 0.216 mg/liter.

Mortalities were counted each day. Dead eggs and sac fry were removed at these times. Also, operation of the apparatus was checked and necessary adjustments were made on a daily basis.

RESULTS

Experiment With Green Eggs

Because of problems encountered in handling green eggs and miscalculations in operation of the dosing apparatus, the first experiment failed to produce the information sought. Copper concentrations (mg/

liter) during this experiment were measured in four test containers and tabulated as follows:

	Control	Low	Medium	High
	0 0	0.129 0.218	0.259 0.448	0.568 0.725
Mean	0	0.174	0.354	0.646

Under these conditions and after 8 days there was almost total mortality in the high and medium concentrations and no mortality in the low concentration and controls. After 10 days the test was terminated with total mortality in the high and medium concentration, 20% in the low concentration, and less than 10% in the controls. Although experimental techniques during this experiment were considered to be unsatisfactory, it was concluded that copper concentrations greater than about 0.1–0.3 mg/liter are acutely toxic to king salmon eggs.

Experiment With Eyed Eggs

In the second experiment, 25-day-old eyed eggs were transported from Coleman National Fish Hatchery to the Water Pollution Control Laboratory and placed in incubation containers with an improved system of water flow control and toxicant dosing. At average measured concentrations of copper of 0.000, 0.021, 0.040, and 0.080 mg/liter (Table 2) there was no detectable difference in the survival of eggs (Table 3). Conversely, at these concentrations mortality among sac fry was a factor at all of the latter three concentrations. Overall survival to the swim-up stage of 0.021, 0.040, and 0.080 mg/liter copper was 67.11, 5.60, and 0.0%, respectively.

TABLE 2

Concentrations of Copper Ion in Mg/Liter in Stock Solution and in Four Test Solutions Used in Bioassay of King Salmon Eggs and Fry

Date	Concentration in mg/liter				
	Stock	Control	Low	Medium	High
Apr. 18, 1969	0.232	0.000	0.025	0.038	0.068
Apr. 22, 1969	0.102	0.000	0.020	0.035	0.102
Apr. 24, 1969	0.265	0.020	0.034	0.044	0.089
Apr. 28, 1969	0.292	0.000	0.034	0.050	0.120
Apr. 29, 1969	0.187	0.000	0.018	0.072	0.078
May 1, 1969	0.224	0.000	0.021	0.035	0.060
May 8, 1969	0.187	0.000	0.007	0.015	0.042
May 13, 1969	0.217	0.003	0.016	0.036	0.081
May 14, 1969	0.235	0.000	0.015	0.038	--
Mean concentration	0.216	0.002	0.021	0.040	0.080
Standard deviation	0.054	--	0.009	0.015	0.024
Standard error	0.018	--	0.003	0.005	0.008

TABLE 3

Percentage Survival and Size Relationships of King Salmon Hatched and Reared in Three Concentrations of Copper Solution

	Concentration of copper in mg/liter			
	0	0.021	0.040	0.080
Number eggs per test	267	377	357	401
Percentage hatch	80.15	75.86	81.79	77.72
Percentage survival to swimup stage	77.15	67.11	5.60	0.00
Percentage survival of sac fry	96.26	88.46	6.85	0.00
Mean size at end of test				
Length in mm	33.5	30.0	26.0	--
Weight in mg	375	326	206	--

Death of fry in 0.080 mg/liter occurred within 1 or 2 days of hatching. A slightly longer time until death was noticed in the 0.040 mg/liter concentration. About 10% of the fry in the 0.040 mg/liter concentration were relatively resistant to copper poisoning and survived for 10 days or more; however, their growth was greatly reduced in comparison with the control fish.

There was a measurable difference in size among the test groups. Fish raised in 0.021 mg/liter copper were measurably smaller than the control fish but larger than those raised in 0.040 mg/liter (Table 3).

DISCUSSION

Working with Atlantic salmon (*Salmo salar*) in soft water, Sprague and Ramsay (1965) found an incipient lethal level of 0.032 mg/liter copper and observed avoidance reactions at concentrations as low as 0.0043 mg/liter. In experiments with Atlantic salmon, Grande (1966) found that copper concentration of 0.02 mg/liter had a marked effect on salmon, and copper in the range 0.04–0.06 mg/liter was noticeably toxic to eggs and fry. Similar values were obtained by Grande using rainbow trout (*Salmo gairdnerii*) and brown trout (*S. trutta*) as test fish. The results of the experiment reported here indicate that the findings of these workers are probably applicable to king salmon. It seems that concentrations of copper as low as 0.02 mg/liter have detrimental effects on salmon fry. Eggs are somewhat more resistant, but short-term exposures to concentrations less than 0.10 mg/liter may have acutely toxic effects.

Further studies, both *in situ* and laboratory, with regard to the possibility of damage to salmonid eggs and preemergent fry in areas receiving unusually large quantities of heavy metals, appear justified.

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VERTICAL MIGRATION OF THE OCEAN SHRIMP, *PANDALUS JORDANI*: A FEEDING AND DISPERSAL MECHANISM[1]

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Ocean shrimp, mainly immature males, were common in nighttime midwater trawl collections off Oregon. They were captured every month of the year except May and June. Annual catches varied greatly at the same stations during 7 years.

Shrimp caught in midwater at night were foraging on euphausiids and copepods. The stomachs of shrimp caught in bottom trawls, on the other hand, contained benthos, but no identifiable pelagic animals. Besides being related to feeding behavior, vertical migration may enhance dispersal of shrimp.

INTRODUCTION

Many species of crustaceans display circadian or diel rhythms of behavior (Bainbridge, 1961; Brown, 1961; Cloudsley-Thompson, 1961; Allen, 1966). Diel changes in the vertical distribution of the ocean shrimp, *Pandalus jordani* Rathbun, are evidenced by day-night differences in catches. Larger day than night catches are reported in bottom trawls, but larger night than day catches are reported from midwater trawls and from baited pots suspended above the bottom (Schaefers and Johnson, 1957; Schaefers and Powell, 1958; Alverson, McNeely, and Johnson, 1960; Milburn and Robinson, in press). These trends indicate that the ocean shrimp migrate off the bottom and into the water column at night.

This paper reports further evidence for pelagic distribution of the ocean shrimp during the night, correlates this behavior with feeding, and speculates on the adaptive significance of such migrations.

METHODS

Pelagic shrimps were collected with 6-ft. Isaacs-Kidd midwater trawls during periods of darkness. A total of 343 collections was made during all seasons from July 1961 to July 1967. A 10-mm (stretch measure) liner was used throughout the trawl net after July 1962. Before this, a 13-mm mesh liner was used in the posterior half of the net and 77-mm mesh in the forward half of the net. Tows were at stations located 15, 25, 45, and 65 nautical miles offshore along 3 latitudes off Oregon: Columbia River (46° 14.4′ N), Newport (44° 39.1′ N), and Coos Bay (43° 20.4′ N). Most collections (235) were made off Newport. Tows were made from the *Acona* or *Yaquina*. The trawl descended at 50 m of wire per minute and ascended at 30 m of wire per minute while the

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ship was under way at 4 to 6 knots. Beyond the continental shelf, tows were to a maximum depth of about 200 m. Over the shelf tows sampled about halfway to the bottom.

Catches were preserved at sea with neutralized formalin, and the shrimps sorted from the collections ashore. Carapace lengths (from base of eyestalk to posterior dorsal margin) of all ocean shrimp were measured to the nearest mm and the occurrence of females carrying eggs was noted.

INSHORE-OFFSHORE DISTRIBUTION

Ocean shrimp were common only at nearshore stations, 15 and 25 miles offshore, where the depth of water was 500 m or less. Only four individuals were captured in trawls farther offshore over deeper water (Table 1). Catches of ocean shrimp were extremely variable. Over 80% of the 1,369 shrimp collected were captured in only 4 collections. The greatest number of shrimp taken in a single catch was 637, or 41 shrimp per 1000 m^3 of water filtered.

TABLE 1

Average Catches of Ocean Shrimp, *Pandalus jordani*, in 343 Midwater Trawl Tows at Stations 15, 25, 45 and 65 Nautical Miles from Shore Along Three Station Lines, July 1961—July 1967

	Columbia River 46° 14.4′ N				Newport 44° 39.1′ N				Coos Bay 43° 20.4′ N			
Miles offshore	15	25	45	65	15	25	45	65	15	24	45	65
No. *P. jordani*	269	0	0	2	732	309	1	1	55	0	0	0
No. tows with *P. jordani*	6	0	0	1	5	27	1	1	2	0	0	0
Av. no. per tow	45	--	--	2	146	11	1	1	27	--	--	--
Total no. tows	15	16	16	11	53	57	61	64	15	15	14	6
Percentage of all tows with *P. jordani*	40.0	0	0	9.1	9.4	47.4	1.6	1.6	13.3	0	0	0

Ocean shrimp was numerically the dominant shrimp species at the 15-mile station off Newport. The shrimp *Sergestes similis* Hansen predominated at all other stations, except at the 15-mile station off the Columbia River, where *Pasiphaea pacifica* Rathbun was numerous (Pearcy and Forss, 1969). Although the average number of shrimp in tows that caught ocean shrimp was highest at the station 15 miles off Newport, 146 per tow, the highest frequency of occurence was found 25 miles off Newport, where ocean shrimp occurred in 47.4% of all tows.

SEASONAL VARIATIONS

Seasonal trends were suggested in the catches of ocean shrimp (Table 2). In general, the largest numbers of shrimp were collected from November to April, while the highest frequency of occurrence was from August to April. No shrimp were found in midwater trawl catches during May and June at any of the stations. Alverson et al. (1960) suggested that vertical movements of ocean shrimp probably are seasonal.

TABLE 2

Monthly Catches of Ocean Shrimp, *Pandalus jordani*, in 140 Midwater Tows at Stations 15 and 25 Miles Off Newport and 15 Miles Off the Columbia River and Coos Bay

Month	J	F	M	A	M	J	J	A	S	O	N	D
Total no. *P. jordani*	197	55	52	232	0	0	12	53	13	12	649	90
Total no. tows with *P. jordani*	8	5	2	5	0	0	2	4	4	3	2	6
Total no. tows	12	16	15	12	5	9	15	0	10	11	9	17
Percentage of all tows with *P. jordani*	66.7	31.2	16.7	41.7	0	0	13.3	41.4	40.0	27.3	22.2	35.3

SIZE STRUCTURE

Ocean shrimp are protandric hermaphrodites; i.e., they are first males and later females, although "primary" females are sometimes found (Butler, 1964). Most of the ocean shrimp taken were small, 8–12 mm carpace length, and represented young-of-the-year males (Figure 1). The mode of 15 mm represents shrimp in their second year (age group I) that were either males or transitional between males and females (Butler, 1964; Robinson and Milburn, 1967). Some egg-bearing females were caught, mainly in a collection 15 miles off Coos Bay in March 1962. Ovigerous females ranged in size from 17 to 25 mm and were probably age groups II and III.

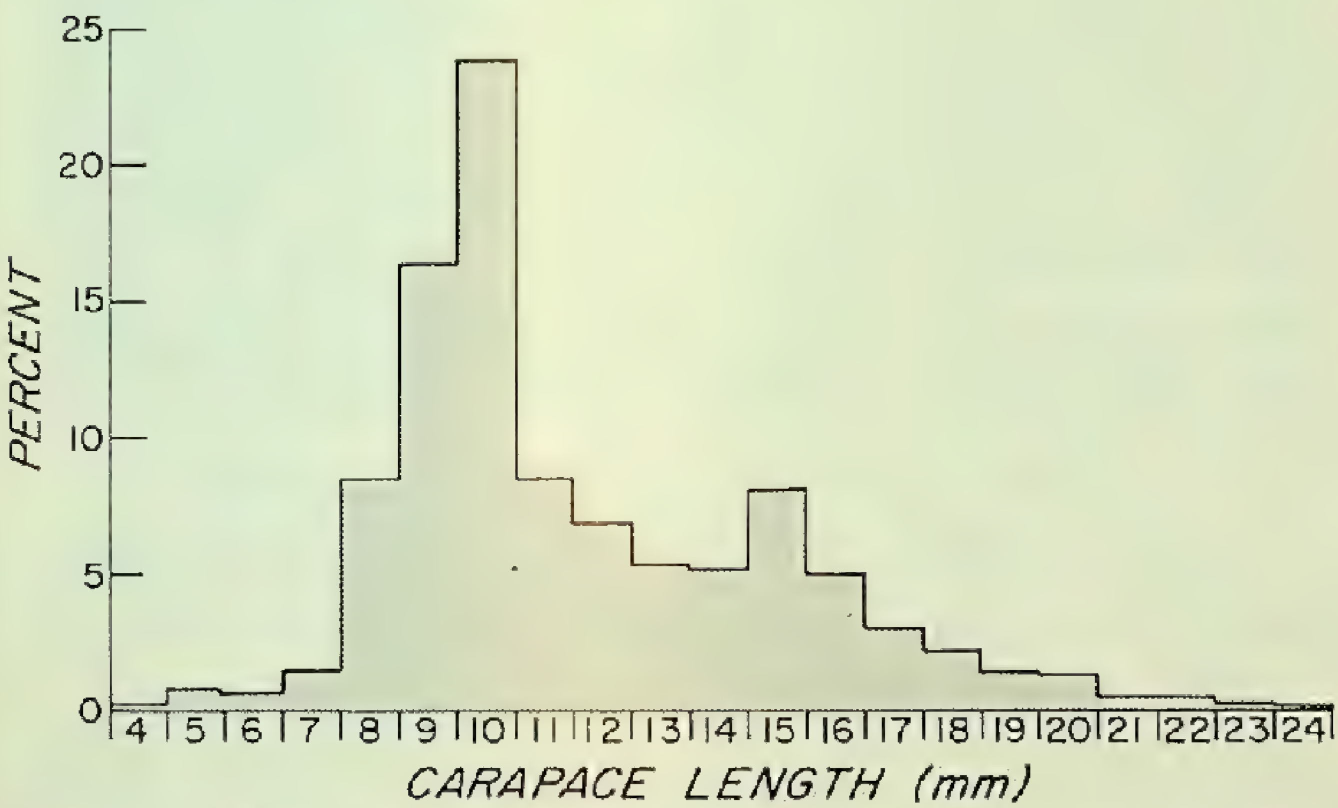

FIGURE 1—Length-frequency distribution of ocean shrimp, *Pandalus jordani*, from all midwater catches.

FOOD HABITS

The stomach contents of 129 shrimp from 18 midwater trawl collections made at various stations and seasons indicated that these shrimp were preying on pelagic animals (Table 3). Euphausiids were the most

common identifiable food, appearing in over 50% of the stomachs. *Euphausia pacifica*, the most numerous euphausiid off Oregon, was identified from many stomachs. Sometimes as many as four euphausiids completely filled a stomach. *Thysanoessa spinifera*, a common neritic euphausiid, was also found. Copepods were the second most common food, occurring in 15% of the stomachs. These included *Calanus finmarchicus*, *Calanus* sp., and *Metrida* sp.

TABLE 3

Items Identified from the Stomachs of 129 Ocean Shrimp Collected at Night in Midwater Trawls

Food item	Number occurrences
Euphausiids	70
Copepods	19
Fish scales	4
Chaetognath jaws	2
Shrimps	2
Amphipods	1
Eggs	1
Polychaetes	1
Sand grains	20
Empty stomachs	48

The stomach contents of 58 shrimp collected in bottom trawls from the same general area were examined for comparison with those of pelagic-caught ocean shrimp. Contents usually consisted of unidentifiable compacted soft material. Sand grains often were present, but these also were found in stomachs of pelagic shrimp. Shell fragments of mollusks and polychaete jaws and setae were sometimes present. Crustacean remains, common in ocean shrimp from midwater, were rare, and identifiable euphausiids and copepods were never found. These marked differences indicate that the shrimp caught in the water column at night were feeding primarily on small pelagic animals, whereas shrimp caught on the bottom were feeding on benthic organisms and "detritus".

ADAPTIVE SIGNIFICANCE OF VERTICAL MIGRATION

These results suggest that the nocturnal migrations of ocean shrimp are related to feeding behavior. Ocean shrimp are exploiting the large biomass of euphausiids and copepods found over the continental shelf off Oregon.

Euphausiids and copepods also migrate vertically and presumably would be close to bottom predators, like ocean shrimp, during daylight hours and near the surface at night. The reason, from an evolutionary viewpoint, why the foraging of ocean shrimp occurs after dark, even though they must migrate far above the bottom to feed at this time, may be their decreased vulnerability to large visual predators. However, pelagic ocean shrimp still may be prey for larger carnivores at night. Gotshall (1969) found that ocean shrimp constituted the dominant food organism of hake, *Merluccius productus*, and arrowtooth flounder, *Atheresthes stomias*, off northern California. He believes that

the vertical migrations of hake may correspond with those of the ocean shrimp.

Perhaps when population density at one location is high, competition for food or space, which leads to increased emigration through increased nocturnal foraging in the water column, may occur. Because shrimp that migrate vertically may be displaced laterally by currents, vertical migrations may also be a dispersal mechanism.

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NOTES

SEA LION CENSUS FOR 1969, INCLUDING COUNTS OF OTHER CALIFORNIA PINNIPEDS

Sea lions are the best known and most often seen of the marine mammals along the California coast. They have long been the subject of controversy between the general public, who see them as interesting and appealing wild animals, and the fishermen, who see them as unmitigated nuisances consuming tons of fish and destroying valuable gear. Unfortunately, the overall relationship of sea lions to other life in the sea is not well known. Because of the conflict of interests involving sea lions, it is important to know the population size of these animals. The California Department of Fish and Game has conducted censuses since 1927; however, before 1946 counts were made of only the animals on the larger rookeries, hauling grounds, and nearby areas. Ripley, Cox, and Baxter (1962) described the methods, problems, and history of censusing sea lions in California.

Interest in the other pinnipeds along our shores has increased in recent years, so these animals were counted in the 1965 census (Carlisle and Aplin, 1966). The 1969 census included California sea lions, *Zalophus californianus*, Stellar sea lions, *Eumetopias jubata*, harbor seals, *Phoca vitulina*, and northern elephant seals, *Mirounga anguistirostris*. No attempt was made to count the northern fur seals, *Callorhinus ursinus*, reported in a small colony on San Miguel Island (Peterson, Le Boeuf, and DeLong, 1968), since only a few individuals would normally be on the rookery in early June.

The 1969 count was made June 3–6 using a twin-engine Cessna Super Skymaster. The plane was flown by Warden-Pilot Leo Singer, who also assisted in the counts. Weather and water conditions were very good during the 4-day census. Skies were overcast during most of the flight, but some sunny areas were encountered and ceilings ranged from 1,500 ft up. Visual counts were made of small aggregations, but large herds were photographed with a K-17 aerial camera. Nine-inch by 9-inch contact prints were viewed under low magnification and the animals tallied. The census area included the entire coast of California and the offshore islands, except the military closures off Fort Ord on Monterey Bay, off Point Mugu, and between Point Sal and Point Conception. Because of heavy air traffic, Santa Monica Bay between Malibu Beach and Malaga Cove and San Diego Bay were not censused. Normally, very few animals frequent these areas.

SEA LIONS

The two species were not separated in the 1969 census. While their ranges overlap to a limited degree in central California during the breeding season (the period of our census), for general purposes those north of Point Conception were considered Stellar sea lions and those south of there California sea lions.

The total number of sea lions in California has remained fairly stable since 1961 (Table 1). An increase has taken place in the northern part of the State since 1965 (Table 1). While there has been a slight increase in southern California, the number of animals on different rookeries varied considerably from the 1961 and 1965 censuses. There has been a steady downward trend in the number of sea lions counted on Santa Barbara Island since 1958. The number of animals on San Miguel Island was less than in 1965, but there were over four times as many on San Nicholas Island.

TABLE 1

Comparison of Sea Lion Distribution on Rookeries and Hauling Grounds, 1958, 1961, 1965, and 1969

	1958	1961	1965	1969
St. George Reef to Cape Mendocino	1,321	907	625	1,069
To Pt. Arena	1,050	781	278	552
To Pt. Reyes	936	795	259	420
To Pigeon Point	90	23	--	263
Farallon Islands	941	703	311	855
Pt. Ano Nuevo	1,170	2,342	2,574	1,985
To Pt. Lobos	517	230	317	488
To Pt. Conception	1,028	894	634	1,524
Northern California	7,053	6,675	4,998	7,156
To Pt. Loma (mainland)	164	33	67	37
San Miguel Island	5,192	9,512	11,641	7,734
Santa Rosa Island	295	--	125	--
Santa Cruz Island	262	15	401	317
Anacapa Island	45	15	--	--
Santa Barbara Island	1,847	1,760	1,100	654
San Clemente Island	1,507	2,361	1,900	667
Santa Catalina Island	233	30	35	107
San Nicholas Island	3,074	4,637	1,900	7,935
Southern California	12,619	18,363	17,169	17,451
Total California	19,672	25,038	22,167	24,607

HARBOR SEALS

Our census data indicate that the harbor seal population has increased since 1965, when the first statewide census of this species was made. Our count of 2,139 animals was over twice the number previously tallied (Table 2). As in the prior census, several areas where a few harbor seals are known to occur (Carlisle and Aplin, 1966) were not included in our count.

An increase in numbers of animals has occurred north of Point Conception. Our count for southern California agreed favorably with Bartholomew (1967), who stated, "the present population of harbor seals in the Southern California Islands is about 500. Although the historical data are incomplete, there is no evidence that their numbers have varied much during the past 40 years."

TABLE 2

Distribution of Harbor Seals During 1965 and 1969 Censuses

	1965	1969
St. George Reef to Cape Mendocino	56	167
To Pt. Arena	304	409
To Pt. Reyes	78	454
To Pigeon Point	250	201
Pt. Ano Nuevo	--	172
To Pt. Lobos	94	41
To Pt. Conception	70	151
To Point Loma	--	7
San Miguel Island	140	64
Santa Rosa Island	--	209
Santa Cruz Island	70	168
Anacapa Island	--	93
	1,062	2,139

NORTHERN ELEPHANT SEALS

A total of 1,642 northern elephant seals was counted during the census. Although this is about half the number counted in 1965 (Table 3), a census conducted by the Department in early April revealed approximately 3,000 elephant seals on San Miguel Island alone (John Carlisle, Jr., California Department of Fish and Game, pers. comm.). Large numbers of animals leave Ano Nuevo Island in late May and early June (Le Boeuf and Peterson, 1968), and probably other islands as well, so counts can vary considerably during this period. The number of elephant seals on a hauling ground may vary as much as tenfold between summer and winter (Bartholomew, 1967). Apparently the animals left the rookeries a little earlier in 1969 than they did in 1965, and were far enough at sea for us to miss them in our census.

TABLE 3

Distribution of Northern Elephant Seals During 1965 and 1969 Censuses

	1965	1969
Point Ano Nuevo	363	172
San Miguel Island	3,000	1,451
San Clemente Island	100	--
San Nicolas Island	100	191
	3,563	1,642

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—Herbert W. Frey and J. A. Aplin, Marine Resources Region, California Department of Fish and Game. *Accepted October 1969.*

FOOD HABITS OF *CLINOCOTTUS ANALIS* (GIRARD)

During a study of the distribution and behavior of the wooly sculpin, *Clinocottus analis* (Girard), the general food habits of the fish were investigated to assess their significance in selection of natural substrates. Little information has been published on the food habits of this species. On the basis of examination of the stomach contents of 12 wooly sculpins (60 to 110 mm TL), Mitchell (1953) concluded that decapod crustaceans comprise the major food of this species, with polychaetes and amphipods consumed to a lesser extent. He found no difference in the type of food eaten by males or females, or by different-sized individuals.

In the present study, the stomach contents of 112 individuals (29 to 127 TL) were examined. All of the fish were collected during July 1967 in the Bird Rock intertidal zone, La Jolla, California. The fish were immediately injected with a 10% formalin solution. Only 2 of the 112 individuals had empty stomachs.

The study indicates that the wooly sculpin is a carnivore which feeds primarily on small invertebrates associated with intertidal plants. Crustacea were the food organisms most often found, occurring in 100 of the 112 stomachs, and contributed a significant amount (53.3%) of the stomach content biomass (Table 1). Amphipods, isopods, and decapod shrimps comprised the major portion of crustaceans eaten. In contrast with Mitchell's (1953) findings, amphipods were the dominant food organism. They comprised 25.7% of the total stomach content biomass and occurred in 86 of 112 stomachs. Decapods and isopods also were important diet components. All other groups, including fish eggs and larvae, polychaete worms, and mollusks were of minor significance, both in terms of frequency of occurrence and biomass contribution.

The color of food items may be of some importance in their attractiveness in relation to the color of the substrates frequented by woolly sculpins. Hemmings (1966) showed the importance of contrasts with the background to visibility in any medium. Since this sculpin was most often found in dark areas between rocks or on dark substrates (Mollick, 1968), light colored food items would tend to be seen and captured more easily. This hypothesis was supported by the results of the stomach analyses, which indicated that 71% of all food items found were white, off-white, or clear in color.

TABLE 1

Major Categories of Food Organisms from 112 *Clinocottus analis* Stomachs

Food category	Mean percentage of wet weight of total food in all stomachs	Number of stomachs containing food category
Crustacea	**59.3**	**100**
Copepoda	0.4	12
Malacostraca		
Amphipoda	25.7	80
Mysidacea	0.2	1
Isopoda	6.3	36
Decapoda		
Macrura	9.4	29
Brachyura	12.2	4
Polychaeta	**2.1**	**9**
Mollusca	**8.1**	**8**
Amphineura	4.8	1
Lamellibranchia	0.2	2
Gastropoda		
Prosobranchia		
Patellacea	3.2	5
Pisces	**4.2**	**11**
Fish eggs	2.9	9
Fish larvae	1.4	2
Unidentified material	**26.3**	**57**

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—*Ronald S. Mollick, Biology Department, Christopher Newport College, Newport News, Virginia.*

A WHITE SEA URCHIN-ACORN BARNACLE ENIGMA

On July 17, 1969, I collected a white sea urchin, *Lytechinus anamesus* H. L. Clark (Figure 1), off San Dieguito Lagoon, near Oceanside, California. This 20-mm animal was found on the open sand at a depth of 60 ft. Attached to it was an acorn barnacle, *Balanus tintinnabulum californicus* Pilsbry.

I have observed thousands of these urchins while diving in southern California and never have seen plants or animals living on one. This lack of encrusting growth is to be expected, since sea urchins normally remove all foreign substances from their test with pedicellariae. Tridentate and ophiocephalous pedicellariae pinch or crush objects within their reach. The trifoliate forms clean small particles from the test's surface and the bases of the spines. Since the globiferous pedicellariae have specialized poison glands, they may keep away or paralyze

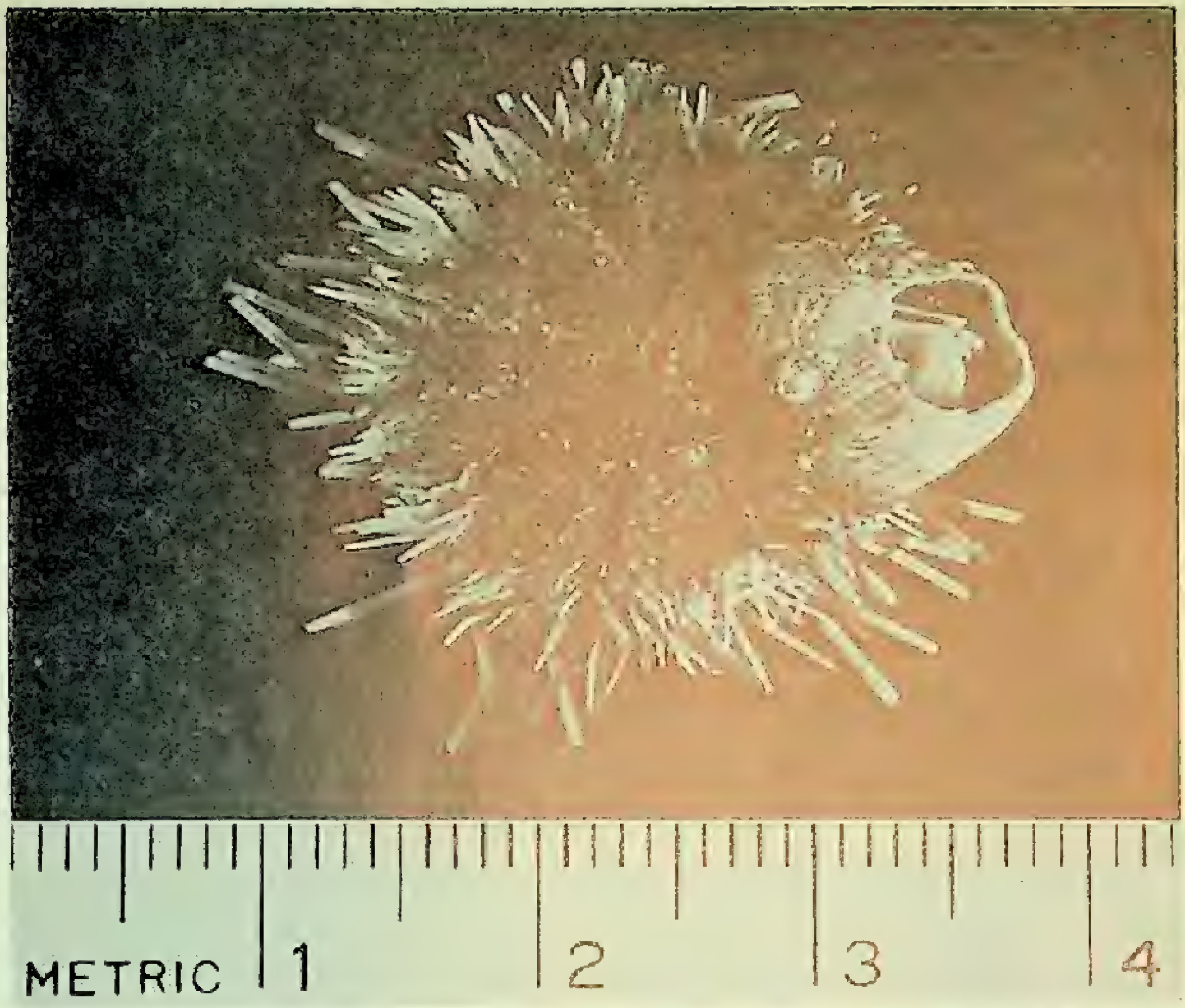

FIGURE 1—An acorn barnacle, *Balanus tintinnabulum californicus*, attached to a white sea urchin, *Lytechinus anamesus*. Photograph by Jason Wasserman.

predators such as starfish (Hyman, 1955). How this acorn barnacle's tiny cyprus larva was able to penetrate the white sea urchin's multiple defense system is indeed puzzling.

To my knowledge this is only the second report of growths on an urchin. Boolootian (1958) reported the same species of barnacle living on a red sea urchin, *Strongylocentrotus franciscanus* (Agassiz). He suggested that an injury to the test may have permitted the attachment of the cyprus.

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—*Alec R. Strachan, Marine Resources Region, California Department of Fish and Game.* *Accepted November 1969.*

THE CALIFORNIA LEAST TERN BREEDING IN ALAMEDA AND SAN MATEO COUNTIES

Grinnell and Miller (1944) gave the status of the California least tern (*Sterna albifrons browni*) as follows: "Now (1943) breeding stations few and sparsely populated, owing to almost complete human use of suitable beaches." They stated further that the northernmost nesting colony was at Moss Landing, Monterey County.

Robert O. Paxton (in Chandik and Baldridge, 1967, p. 602) reported that three nests of least terns were located at Alameda, Alameda County, in June 1967.

Least terns were observed in South San Francisco Bay during August and September 1968. The highest number seen was about 60, on September 1. On the strength of this evidence and the Paxton report, a concerted effort was made in the spring and summer of 1969 to locate breeding colonies of least terns in the San Francisco Bay complex.

BREEDING COLONIES

Since the nesting requirements of this species demands a certain degree of isolation, the only site in the general vicinity of Alameda which seemed to meet these requirements was Bay Farm Island. Until 4 years ago this was a prime quality marsh, but since then it has been dyked and filled.

On July 2, Don Knapp of the U. S. Bureau of Sports Fisheries and Wildlife and I located a nesting colony of least terns on Bay Farm Island. The colony was widely scattered over at least 200 acres of sandy flats, rendering it extremely difficult to estimate the size of this breeding population. It involved approximately 30 pairs. One nest containing three eggs was found, as were also several young, ranging in development from downy stage to fully feathered. Flightless young were difficult to find because of their characteristic habit of "freezing". The following day two more nests were found, each containing two eggs, and a few more fledglings were located and photographed.

On July 8 a trip was made to Bair Island, San Mateo County, and least terns were found nesting here. One nest with a single egg was located. On July 12 seven nests, each containing two eggs, were found on Bair Island. No young terns were seen. It is of interest that no least terns were in evidence on a visit to Bair Island on June 23. It is, therefore, assumed that the Bair Island colony represents a recent invasion, possibly from Bay Farm Island, where construction activities may have led some of the birds to move to another site.

The Bair Island nesting area is a salt flat which was formed after a vernal pool had receded. Much of the area was crossed by deep cracks. The nests were on slightly elevated ground where the terrain was relatively smooth. The population was estimated at 15 pairs.

Bay Farm Island was revisited on August 9. No least terns were in evidence, and it was assumed that the breeding cycle had terminated. However, about 80 least terns were seen on the same day near Dumbarton Bridge, Alameda County. Some were observed feeding fully grown young. The small sample of birds visible on the ground indicated an old-young ratio of approximately 2:1.

Unfortunately, both of the least tern nesting colonies are in grave jeopardy because they are on sites which are in the paths of housing developments. It may be possible to retain this interesting species as a breeding bird in San Francisco Bay by providing an area elsewhere which would meet its nesting requirements and, hopefully, attract this pioneering population.

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—*William Anderson, Wildlife Management Branch, California Department of Fish and Game.* *Accepted November 1969.*

OLDEST TAGGED NORTHERN ELEPHANT SEAL RECOVERED IN OREGON

Recently I reported on the extension of range of shore occupation by the northern elephant seal, *Mirounga angustirostris,* (Mate, 1969). This observation was of two immature males judged to be almost 1 and 2 years old during September and October 1968.

On July 8, 1969, two other male elephant seals were observed hauled out on the solid rock area of Simpsons Reef, Cape Arago State Park, Charleston, Oregon. These animals were much older; the larger measured approximately 12–13 ft in total length and carried a monel tag on the skin of the left front flipper. A check with the records kept by Richard S. Peterson at the University of California, Santa Cruz, indicated that this animal (tag no. 20) had been born during the 1962–1963 breeding season on Ano Nuevo Island, California, 460 miles south of Simpsons Reef. It was tagged by Richard Jennings of Stanford Research Institute, Menlo Park, California, on February 17, 1963. At that time the animal was close to weaning and weighed 390 lb. The animal is therefore 6½ years old. The other animal appeared to be one year younger. Both animals had no wounds or scars and appeared in excellent condition. Both were marked with a commercial hair bleach, Lady Clairol Ultra-blue: the older one with an 8-inch letter "Q" behind the front flipper on the left side, and the younger one with a solid circle of the same size above each shoulder. As both animals showed signs of just completing their moult, these markings should be visible until next year.

The larger animal was observed until July 19, 1969, and the smaller one was last seen on July 22, 1969. Discovery of the tagged individual is significant since it represents the oldest tagged elephant seal recovered to date.

REFERENCE

Mate, Bruce R. 1969. Northern extension of range of shore occupation by *Mirounga angustirostris,* Jour. Mammal., 50 (3) : 639.

—*Bruce R. Mate, Oregon Institute of Marine Biology, Charleston, Oregon 97420.* *Accepted December 1969.*

ADDITION OF HART'S RIVULUS, *RIVULUS HARTI* (BOULENGER), TO THE CALIFORNIAN FAUNA

On January 13, 1967, I observed and collected *Rivulus harti*, a South American cyprinodont, in a small ditch below the Hot Mineral Spa adjacent to Del Rancho El Sargent, a tropical fish farm in Imperial County. The specimens represent the first confirmed record of *R. harti* in California. Other species found in the ditch were mosquitofish, *Gambusia affinis;* mollies, *Poecilia latipinna* and *P. mexicana mexicana;* desert pupfish, *Cyprinodon macularius;* and *Tilapia mossambica*. The ditch is located on the eastern side of the Salton Sea. It is here that *Tilapia mossambica* was first discovered, in 1964 (St. Amant, 1966).

The first specimen, collected on January 13, 1967, measured 35 mm. Carl L. Hubbs identified it as *R. harti*. Additional specimens collected on November 13, 1968, were also identified by Hubbs as *R. harti*. These included one adult male and two adult females measuring 42 to 45 mm SL. I also collected additional adults, as well as juveniles, during inspection trips in 1969.

Since *R. harti* were once reared at the tropical fish farm, I believe it to have been the source of the introduction. The fish farm is now closed.

REFERENCE

St. Amant, James A. 1966. Addition of *Tilapia mossambica* Peters to the California fauna. Calif. Fish and Game, 52 (1) : 54–55.

—*James A. St. Amant, Inland Fisheries, Region 5, California Department of Fish and Game.* *Accepted December 1969.*

DIFFERENTIAL DISTRIBUTION OF THE STRIPED MULLET, *MUGIL CEPHALUS* LINNAEUS

The striped mullet, family Mugilidae, is present in coastal waters and estuaries of the tropical and subtropical zones, roughly between latitudes 42 N and 42 S (Thomson, 1963). Current literature suggests that the striped mullet is catadromous, but conflicting reports on the nature of the life history are common (Breder and Rosen, 1966, p. 366–368).

In 1967 and 1968 striped mullet were collected at approximately 2-month intervals from Hunters Hole, a slough near Gadsden, Arizona, and from below Imperial Dam, 110 and 150 miles, respectively, upstream from the Gulf of California. Marine collections were made during the same months at El Golfo de Santa Clara, Sonora, Mexico, near the Colorado River delta. These collections were made during a study of the effects of seasonal factors and reproductive and migrational activities associated with variations in salinity on the histology of certain endocrine organs of the striped mullet (Johnson, 1969).

Striped mullet collected comprised the following five distinct size groups (standard length): (i) 7–13 cm in Gulf collections during July, August, and September; (ii) 17–20 cm, in Gulf collections; (iii) 21–28 cm, in Gulf and Hunters Hole collections; (iv) 29–37 cm, in

Gulf, Hunters Hole, and Imperial Dam collections; and (v) 39–46 cm, in Gulf and Imperial Dam collections. The mean standard length and 95% confidence limits for 86 fish collected from the Colorado River was 33.1 ± 1.4 cm, while that for 756 El Golfo fish was 22.4 ± 1.7 cm. Larger size classes were difficult to collect in Gulf waters. Gear selectivity appeared not to be a factor in the absence of smaller size classes in river samples. According to growth rates reviewed by Thomson (1963), fish in groups (i) were approaching age 1, (ii) age 1 and 2, (iii) age 2, (iv) age 3 and 4, and (v) age 4 and 5. The correlation of progressively larger size classes with distance from the Gulf indicates an extremely slow, alimental upstream migration of striped mullet. These findings support a marine origin for the striped mullet of the Colorado River.

On March 19, 1966, however, a collection of 31 postlarval striped mullet (A.S.U. No. 2293) was made below Morales Dam, Colorado River, 120 miles upstream. Their mean standard length was 32.4 ± 1.1 mm, with a range of 28–40 mm. The size of the postlarvae indicates they were progeny from spawning that occurred in December and January. Since they were collected such a great distance from salt water, it appears that they arose from spawning of striped mullet in fresh water. Larval mullet have been reported to enter Australian estuaries when large enough to swim against tidal streams, 2–3 months after hatching (Thomson, 1963); however, this is the first time they have ever been reported this far upstream at this stage of their life history. These findings put in question any salinity requirement for successful striped mullet spawning.

ACKNOWLEDGMENTS

Numerous graduate students and friends assisted with seining. The beach seine was loaned by Sr. Ramon Lopez of Santa Clara. The cooperation of Juan Lopez of El Golfo Sport Fishing Resort was invaluable. We also are indebted to W. L. Minckley and J. W. Emig for their editorial assistance.

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Thomson, J. M. 1963. Synopsis of biological data on the grey mullet, *Mugil cephalus* Linnaeus 1758. CSIRO Fish. and Oceangr., Fish. Synopsis No. 1. 65 p.

—Donald W. Johnson and Emmitt L. McClendon, Department of Zoology, Arizona State University, Tempe, Arizona (now with University of California, Bodega Marine Laboratory, Bodega Bay, California 94923 and Inland Fisheries Branch, California Department of Fish and Game, Sacramento, California 95814, respectively).
Accepted December 1969.

BOOK REVIEWS

Advances in Ecological Research, Volume 5

Edited by J. B. Cragg; Academic Press, London and New York, 1968; xi + 283 p., illustrated. 80s.

The first in this collection of research papers, "Toward Understanding Ecosystems", was prepared by David M. Gates, Missouri Botanical Gardens. He attempts to couple environment to botanical organisms in terms of energy flow and uses a series of mathematical models to answer quantitatively various ecological questions.

A. R. Main of the University of Western Australia incorporates previous findings and those of his own in "Ecology, Systematics and Evolution of Australian Frogs". He explores all facets of the ecology and taxonomy involving the 22 species of Anura found in Australia, while offering feasible evolutionary trends. Main concludes his paper with an unusually extensive bibliography.

"Studies on the Insect Fauna of Scotch Broom, *Sarothamus scoparins* (L.) Wimmer", by N. Woloff, Imperial College, England, delves into the insect "community" relationship using the relatively short-lived host, broom, as the habitat.

The final paper in this outstanding edition, "Ecology of Fire in Grasslands", by R. Daubenmire, Washington State University, is a very well written technical paper which makes for pleasurable and informative reading. He has documented a great deal of conflicting literature on the subject of burning as a range management tool. It will certainly be of particular value to range management scientists —*J. R. Bybee.*

Living Turtles of the World

By Peter C. H. Pritchard; T. F. H. Publications, Inc., Jersey City, N. J., 1967; 288 p., profusely illustrated in color and black-and-white. $9.95.

Pritchard's purpose is to bridge the gap between the popular and the specialized books on turtles. He accomplishes this by describing all the known species, and includes a panoramic look at the 12 recognized families. Because of such wide coverage, the discussions of individual species are extremely brief, being limited mainly to description, range, and interesting life history data. Although living turtles are the main subject, the author finds it necessary occasionally to discuss extinct species. This is acceptable, however, since it provides the reader a picture of chelonian evolution.

A brief chapter considers man's relationship with turtles, in particular the reduction of turtle populations through overexploitation for use as food and in the pet trade. The hawksbill turtle, *Eretmochelys imbricata*, having the misfortune to possess a thick, lustrous shell desired by man, is heavily fished throughout most of its range. Although the hawksbill is not always killed (the overlapping plates are removed by heat from the live animal), it is doubtful that many survive to grow a new cover.

The chapters devoted to each family are followed by sections on turtle reproduction in general and the breeding habits of sea turtles. The section which discusses turtles in captivity includes methods of capture, selection of specimens, and their care. A bibliography of 41 selected references and a glossary conclude the book.

Biologists and students will find *Living Turtles of the World* a valuable reference. Hobbyists should also find this book of use, particularly the chapter "Turtles in Captivity". The color and black-and-white photographs are well done and are helpful in identification.—*James A. St. Amant.*

Biological Aspects of Thermal Pollution

Edited by Peter A. Krenkel and Frank L. Parker; Vanderbilt University Press, Nashville, Tennessee 37203, 1969; xx + 407 p., illustrated. $7.95.

Engineering Aspects of Thermal Pollution

Edited by Peter A. Krenkel and Frank L. Parker; Vanderbilt University Press, Nashville, Tennessee 37203, 1969; xxi + 351 p., illustrated. $7.95.

The above two volumes represent the proceedings of the National Symposium on Thermal Pollution, sponsored by the Federal Water Pollution Control Administration and Vanderbilt University. The symposium was held in two sessions, the first at Portland, Oregon, June 3-5, 1968, and the second at Nashville August 14-16, 1968.

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Notice is hereby given that the Fish and Game Commission shall meet on April 3, 1970, at 9:00 a.m. in the Auditorium of Office Building No. 8, 714 P Street, Sacramento, California, to receive recommendations from its own officers and employees, from the Department of Fish and Game and other public agencies, from organizations of private citizens, and from any interested person as to what, if any, orders should be made relating to birds or mammals, or any species or variety thereof for the 1970 hunting season.

Notice is hereby given that the Fish and Game Commission shall meet at 9:00 a.m. on May 1, 1970, in Room B109, State Building, 1350 Front Street, San Diego, California, for public discussion of and presentation of objections to the proposals presented to the Commission on April 3, 1970, and after consideration of such discussion and objections the Commission shall publicly announce the regulations it proposes to make relating to birds or mammals, or any species or variety thereof, for the 1970 hunting season.

Notice is hereby given that the Fish and Game Commission shall meet on May 29, 1970, at 9:00 a.m. in Room 1138 of the New State Building, 107 South Broadway, Los Angeles, California, to hear and consider any objections to its determinations or proposed orders in relation to birds and mammals for the 1970 hunting season, such determinations resulting from hearing held on May 1, 1970. This notice is published in accordance with the provisions of Section 206 of the Fish and Game Code.

Fish and Game Commission
Leslie F. Edgerton
Executive Secretary

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